AD-A152 234 AN EVALUATION OF THE PERFORMANCE OF A NEW STORM TRACKING METHODOLOGY(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA T JAYACHANDRAN SEP 84 NPS-53-84-0007 1/1

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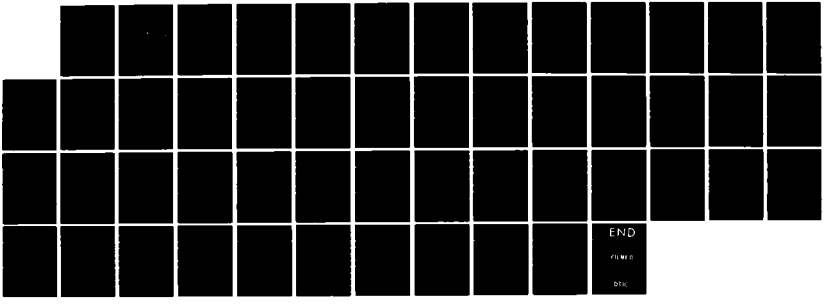

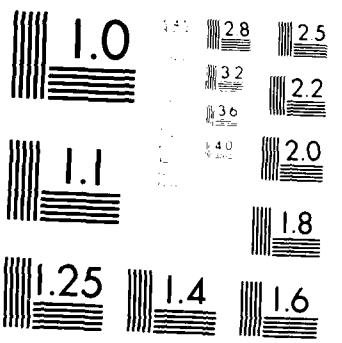

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AN EVALUATION OF THE PERFORMANCE OF
A NEW STORM TRACKING METHODOLOGY

by

Toke Jayachandran

September 1984

Technical Report For Period
October 1983 - September 1984

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Prepared for:
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Monterey, CA 93943

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Dean of Information & Policy Sciences

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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This report contains the results of an exploratory statistical analysis to evaluate the performance of the Systematic Error Identification System (SEIS) and the Vortex Tracking Program (VTP), when tracking weather systems.

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ABSTRACT

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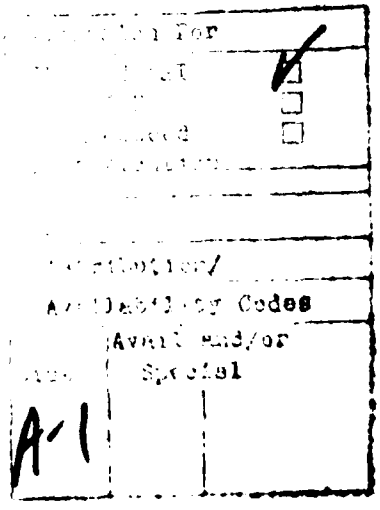


AN EVALUATION OF THE PERFORMANCE OF A NEW STORM TRACKING METHODOLOGY

1. Introduction

Weather forecasts made by the Fleet Numerical Oceanography Center (FNOC) are based on a numerical weather prediction model called the Naval Operational Global Atmospheric Prediction System (NOGAPS). Until 1983 the only available measures of model performance were of a global nature (aggregated over all the weather systems monitored), such as means, variances and root mean square errors. The operational field forecasters, on the other hand, prefer error statistics relevant at the synoptic level, i.e., measures pertaining to forecasts of individual storms and troughs. Such measures would enable these forecasters to provide better subjective forecasts at the regional level. In 1982, the Naval Environmental Prediction Research Facility (NEPRF) began the development of the Systematic Error Identification System (SEIS); the primary data reduction methodology within SEIS is the Vortex Tracking Program (VTP). In the VTP, an atmospheric low/high pressure system is mathematically represented as a generalized six parameter elliptic function. The six parameters correspond with the primary features of a storm, viz., the amplitude A, R the semi-major of the elliptic representation of the storm, ε the eccentricity or the ratio of the semi-major to the semi-minor, α the orientation of the ellipse and X_o, Y_o the coordinates of the center of the storm. The units of measurement are millibars (mb) for A, and degrees with respect to the North for α while R, X_o, Y_o are measured in terms of a 63x63 FNOC hemispheric grid units. For each valid storm, the VTP uses an iterated non-linear least squares scheme to estimate A, R, ε, α, X_o, Y_o within the sea level pressure field for the analysis at time t as well as for the associated 12, 24, 36, 48 and 60 hour forecasts produced by NOGAPS. The iteration scheme requires a set of initial guess values for the parameters to produce the estimates for the analysis field at time t. These estimates are in turn used as guess values to produce the 12 hour forecasts; the 12 hour parameter

forecasts are used to generate the 24 hour forecasts and so on. The estimated parameter values for the analysis field at time t are also used as the first guesses for the analysis field at t + 12 hours. The estimates for the analysis field are usually referred to as verification values. Corresponding to each set of forecasted parameter values there will be a verification set obtained using the current (for the forecasted time) sea level pressure data. The difference between a forecasted value and its verification value is called the forecast error. SEIS, thus, provides the capability to track individual weather systems (by tracking the movement of the elliptic representation) and also a means to measure and analyze the tracking errors.

The modified NOGAPS model has been running on a real time basis since mid 1983. During the life cycle of each valid storm, twice each day (at noon and at midnight GMT), the elliptic parameter estimates are produced for the analysis field and the associated 12, 24, 36, 48 and 60 hour forecast fields. References [1], [2] and [3] discuss the VTP and SEIS models in more detail.

The objective of this project is the exploratory statistical analysis of the forecast errors to assess the performance of the SEIS/VTP model. Data on 80 storms, covering the North Pacific Ocean Basin, observed during the period January-May 1984 has been used in this study. The results of the analysis are described in the following sections. Section 2 contains overall measures of performance of SEIS/VTP, primarily summary statistics of forecast errors pooled over all the 80 storms. Error statistics pertaining to the tracking of individual storms are presented in Section 3. Conclusions and topics for further research are discussed in Section 4.

2. Analysis of Forecast Errors

A forecast error is defined as the difference between a forecasted parameter value and its verification value; an absolute forecast error is the absolute value of a forecast error. For each of the five forecasting periods (12, 24, 36, 48 and 60 hours) the forecast and the absolute forecast errors were subjected to various statistical analyses. Tables 1 and 2 contain the means ($\bar{X}$) and standard deviations (S) for these errors.

TABLE 1

SUMMARY STATISTICS OF FORECAST ERRORS

Forecast Period	Number of Samples	A		ε		R		α		X_0		Y_0	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
12	487	-1.53	5.20	-0.05	1.49	0.21	1.27	4.75	49.83	-0.06	0.77	0.13	0.
24	429	-2.67	6.69	-0.07	1.47	0.19	1.38	4.60	52.14	-0.08	1.01	0.10	1.
36	371	-4.11	7.68	-0.13	1.86	0.27	1.73	4.83	56.10	-0.14	1.22	-0.04	1.
48	329	-5.14	8.50	-0.18	1.84	0.28	1.76	5.51	53.95	-0.11	1.34	-0.01	1.
60	288	-5.08	9.61	-0.30	2.03	0.21	1.85	5.10	50.85	-0.09	1.45	-0.14	1.

TABLE 2

SUMMARY STATISTICS OF ABSOLUTE FORECAST ERRORS

Forecast Period	Number of Samples	A		ε		R		α		X_0		Y_0	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
12	487	3.87	3.79	0.85	1.23	0.85	0.98	28.79	40.93	0.50	0.59	0.55	0.
24	429	5.56	4.57	0.92	1.15	1.00	0.98	32.65	40.89	0.69	0.73	0.78	0.
36	371	6.84	5.89	1.07	1.52	1.19	1.28	37.26	42.18	0.87	0.86	1.02	1.
48	329	7.68	6.32	1.07	1.51	1.19	1.32	36.65	39.92	0.97	0.93	1.23	1.
60	288	8.38	6.92	1.20	1.67	1.20	1.42	35.20	36.99	1.04	1.01	1.36	1.

The following general conclusions appear warranted. The NOGAPS forecasting methodology does forecast the parameters A, R, ε, X_o, Y_o quite well. With regards to the forecasting of the orientation α, although the mean errors are not excessive, the standard deviations are somewhat high. In many cases the forecast errors are negative indicating a negative bias, i.e., the forecasted values tend to be on the low side of the verification values. With a few exceptions, the means and standard deviations increase with an increase in the forecasting period; this is to be expected in view of the higher levels of uncertainty involved.

The autocorrelations for lags 1 to 5 between the forecast errors are presented in Table 3. Except for the lag-one autocorrelations of about .30 for the forecast errors of A, X_o, Y_o the rest of the autocorrelations are quite negligible. This implies that a large error in forecasting a parameter at a given time will not have a lasting effect on future forecast errors. Also, the correlation matrices (correlations between the errors in forecasting A, α, R, ε, X_o, Y_o) in Table 4 show that these correlations are negligible with one exception -- the correlation between the errors in forecasting R and ε is around .5. This may be interpreted to mean (with the one exception) that a large forecast error for one parameter will not have a detrimental effect on the estimates of the other parameters.

In an attempt to model the statistical behavior, gamma distribution were fit to the 12, 24, 36 and 48 hour absolute forecast errors. The histograms with the fitted gamma distribution superimposed are in Figures 1-18. Gamma distributions appear to serve as good statistical models of the absolute forecast errors for A and R. In the other cases, the lack of fit may be attributed to a higher peakedness in the data; a Weibull distribution may provide a better fit. Although no graphs are presented, gamma distributions did not provide a good fit to the forecast errors (appropriately translated/shifted to make them positive) also. Further work will be necessary to determine the most appropriate statistical distributions to model the probabilistic behavior of the forecast errors. Proper statistical modeling of the error data could be useful for exploring the development of uncertainty contours (confidence regions) for the movements of weather systems.

TABLE 3

AUTOCORRELATIONS BETWEEN THE FORECAST ERRORS

	12 Hr Forecasts					24 Hr Forecasts					36 Hr Forecasts					48 Hr Forecasts					60 Hr Forecasts				
	Lag					Lag					Lag					Lag					Lag				
Parameters	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
A	.13	.04	-.05	-.02	.04	.33	.11	-.06	-.09	-.10	.35	.02	-.07	-.05	-.05	.31	-.04	-.04	-.03	-.07	.28	.02	.01	.01	-.02
ε	.04	.07	-.10	-.01	-.01	.14	-.12	-.06	.03	-.01	.04	0	-.01	-.06	0	.14	-.07	-.02	-.04	-.01	.16	-.03	.07	.11	.05
R	.02	.10	.08	.05	0	.21	0	.03	.08	-.05	.29	.06	0	.03	.02	.31	.03	.03	-.03	-.05	.18	-.03	0	-.03	.04
α	-.05	-.01	-.05	-.01	.02	-.04	.03	0	-.07	.02	-.03	.04	-.02	.03	-.02	-.06	.04	.01	.06	.04	.10	.06	.05	.02	-.08
X_0	.06	.05	0	-.04	-.06	.25	.05	-.07	-.01	-.03	.34	.06	.03	-.05	-.05	.41	.07	-.05	-.04	-.03	.29	.07	-.05	-.02	0
Y_0	.22	.11	.10	-.02	-.07	.28	.08	-.02	.04	.07	.29	.11	.08	0	.06	.36	.06	0	-.04	.07	.36	.06	.02	-.09	-.09

TABLE 4

CORRELATION MATRICES FOR FORECAST ERRORS

Para-	12 Hr Forecasts						24 Hr Forecasts						36 Hr Forecasts						48 Hr Forecasts						60 Hr Forecasts					
meters	A	ε	R	α	X_0	Y_0	A	ε	R	α	X_0	Y_0	A	ε	R	α	X_0	Y_0	A	ε	R	α	X_0	Y_0	A	ε	R	α	X_0	Y_0
A	1	.08	-.03	.09	.14	.02	1	.18	.07	.07	.10	.03	1	.10	0	-.10	.04	.10	1	.23	.03	.04	-.04	.15	1	.19	.01	.15	-.04	.12
ε	.08	1	.48	.11	.06	-.08	.18	1	.55	.02	.15	0	.10	1	.48	.02	.17	-.05	.23	1	.54	.04	.12	.05	.19	1	.57	.05	.08	-.08
R	-.03	.48	1	.09	-.19	.01	.07	.55	1	-.04	-.13	.05	0	.48	1	-.04	-.11	.07	.03	.54	1	0	-.09	.12	.01	.57	1	-.05	-.05	-.06
α	.09	.11	.09	1	.04	0	.07	.02	-.04	1	.01	-.01	.10	.02	-.05	1	-.04	-.08	.04	.04	0	1	-.02	-.10	.15	.05	-.05	1	.05	-.15
X_0	.14	.06	-.19	.04	1	-.11	.10	.15	-.13	.01	1	-.22	.04	.17	-.11	-.04	1	-.20	.04	.12	-.09	-.02	1	-.22	.04	.08	-.05	.05	1	-.16
Y_0	.02	-.08	.01	.00	-.11	1	.03	0	.05	.01	-.22	1	.10	.05	.07	-.08	-.20	1	.15	.05	.12	-.10	.22	1	.12	-.08	-.06	-.15	-.16	1

3. Statistics of Individual Weather Systems

To evaluate the performances of SEIS, in tracking individual weather systems, and the NOGAPS model in forecasting weather systems, data on 20 storms with at least 10 records per storm (i.e., 10 sets of forecasted and verification values per storm) were examined. The means $(\bar{X})$ and standard deviations (S) of the forecast errors for these 20 storms are in Table 5.

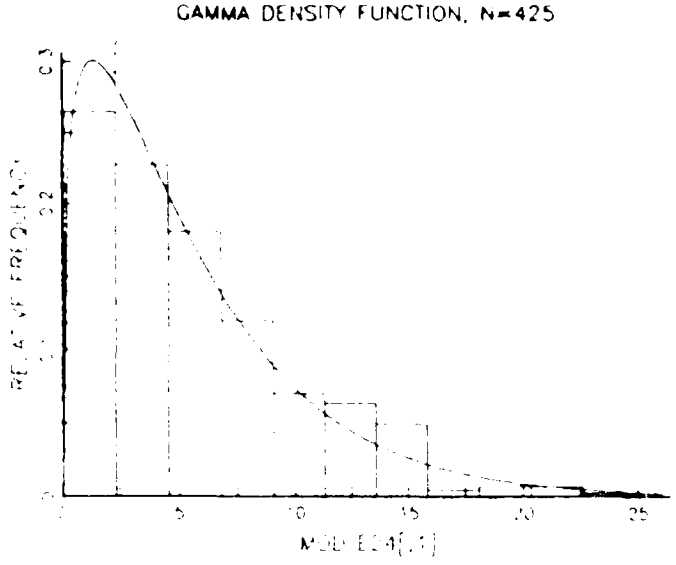
The trends in the forecast errors are similar to the global trends observed in the previous section; with the exception of the forecasting of α, the forecast errors are very small even at the individual storm level. The iterated non-linear least square procedure in VTP requires initial guess values for each of the parameters A, ε, R, α, X_o, Y_o; the initial guess for α is always specified as zero. We conjecture that this may be the cause of the somewhat erratic forecasts of α. A better initial guess, closer to the true value, may result in a better forecast of α. The SEIS/VTP appears to be exceptionally good in forecasting the center of a storm.

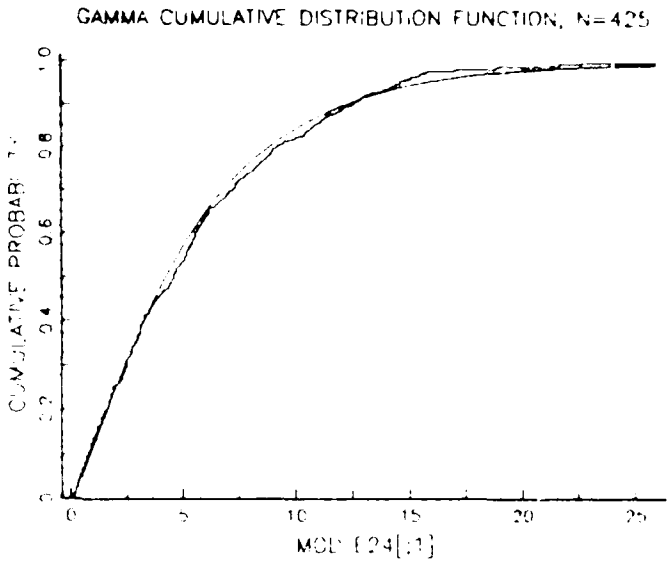
For each of the 20 storms the forecasted values of A, X_o and Y_o were plotted against their respective verification values. In several cases, the scatter plots indicated an approximate linear relationship between the forecasted and verification values. A few of these scatter plots are shown in Figures 19-30. A linear regression analysis was, therefore, performed with the forecasted value as the independent variable and the verification value as the dependent variable. The least squares estimates of the intercept and slope of the fitted line and also the estimated coefficient of correlation (a measure of goodness of the fitted line) are in Table 6.

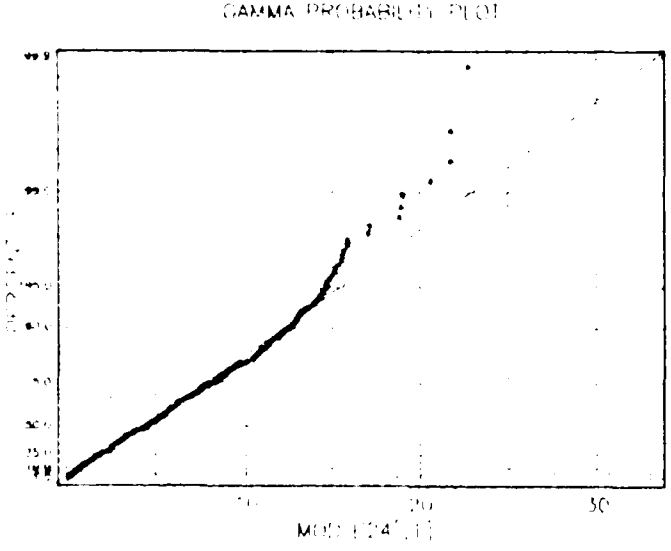
TABLE 5

SUMMARY STATISTICS OF FORECAST ERRORS FOR INDIVIDUAL STORMS

torm umber	Number of Records	A		ε		R		α		x_0		x_0	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	19	-9.9	5.2	0.6	1.3	0.8	1.5	4.4	99.0	5.3	0.8	0.1	0.3
2	18	-10.3	5.1	0.5	1.2	0.7	1.5	4.0	101.7	0.1	0.8	-0.1	0.3
3	34	-1.2	4.9	-0.6	1.5	-0.3	1.9	9.3	24.5	-5.2	0.7	-1.1	1.4
4	18	-6.4	5.1	-0.7	2.8	0.5	2.8	-3.3	20.3	1.1	1.4	-0.8	1.3
5	60	-5.6	10.1	0.1	0.9	0.6	1.4	-5.0	35.5	0.4	1.1	-0.5	1.8
6	19	-1.8	3.9	-0.2	1.0	1.4	1.7	6.9	31.3	-1.7	1.3	3.2	1.8
7	27	1.3	3.9	0.1	0.4	0.5	0.9	34.9	32.5	0.1	0.8	-0.9	1.4
8	41	-8.0	9.3	-1.3	3.3	0.7	2.3	3.5	47.2	-0.7	1.3	0.7	1.4
9	25	-3.2	16.0	-2.6	4.0	-0.5	1.4	11.0	74.8	-1.1	1.6	0.5	0.8
10	26	4.8	7.2	-0.1	2.4	0.4	1.1	-13.4	86.2	0.8	1.6	-0.4	0.5
11	23	-6.5	12.8	0.4	0.6	0.7	1.6	9.3	55.5	0.1	1.3	0.0	0.5
12	13	0.4	5.5	1.5	2.3	0.2	0.7	-10.7	29.2	0.1	0.9	0.0	0.5
13	63	-2.4	8.3	-0.1	1.7	-0.3	1.1	-6.9	54.4	0.5	1.1	0.8	0.6
14	10	-11.6	9.6	-0.1	0.8	-0.8	1.1	22.1	66.6	1.0	1.0	-0.2	0.5
15	20	-0.7	6.8	0.9	1.4	0.9	2.1	-7.3	36.7	1.2	2.0	-0.9	2.0
16	27	-2.0	6.7	-1.1	1.2	-0.9	2.0	7.5	33.0	-0.1	1.3	0.1	1.2
17	13	-6.6	4.2	-0.3	0.7	-0.7	0.8	-17.6	17.2	0.0	0.5	0.3	0.5
18	93	-3.4	6.7	-0.2	1.1	0.2	1.5	12.9	52.0	0.2	1.1	0.9	2.2
19	72	-5.1	9.4	0.3	1.4	-0.1	1.1	-11.0	54.8	0.1	1.0	0.1	1.9
20	71	-3.8	6.5	-0.5	2.7	-1.3	2.9	-20.1	36.8	-0.4	0.5	0.7	0.7







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90	12.5	12.148
95	14.6	15.406

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0083156	0.021433
BETA	0.021433	0.10759

GOODNESS OF FIT

CHI SQUARE	17.153
DEG FREED	7
SIGNIF	0.01644
KOLM SMIRN	0.039736
SIGNIF	0.51378
CRAMER V M	0.12906
SIGNIF	* .10
ANDER DARL	0.88782
SIGNIF	* .15

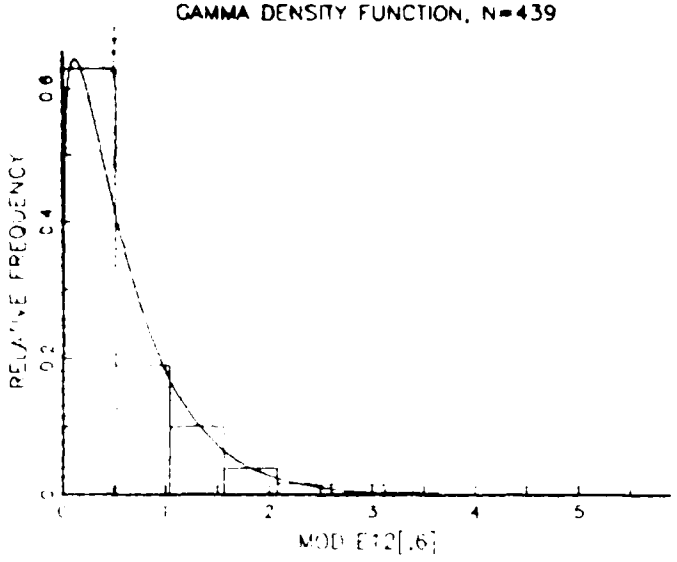
KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

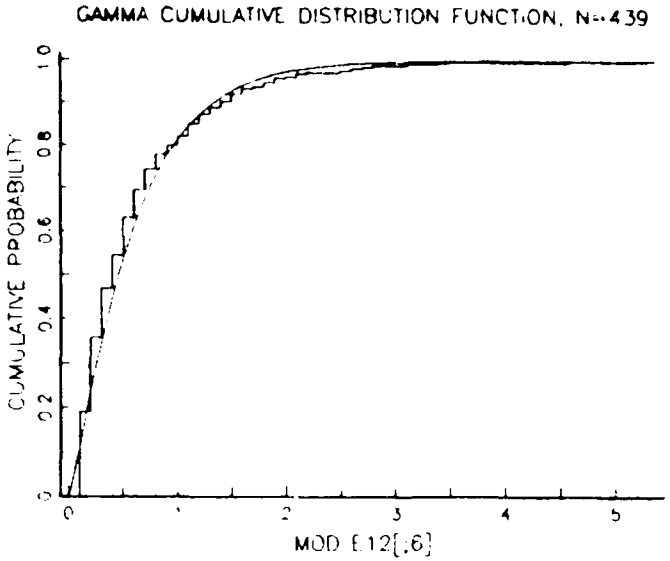
0.95 CONFIDENCE INTERVALS

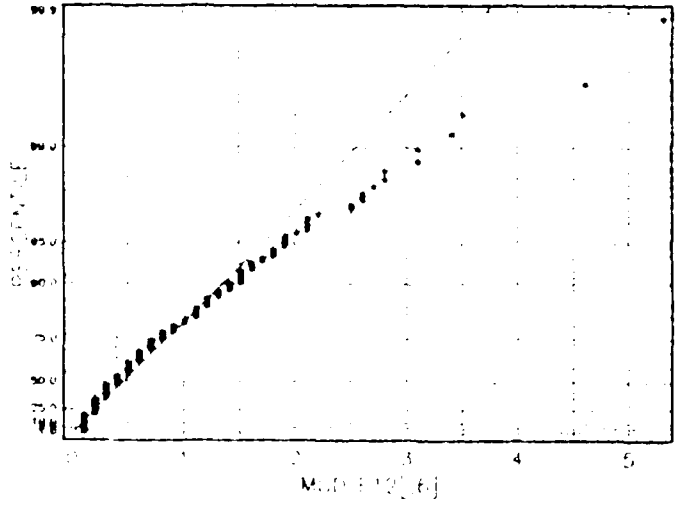
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.2842	1.1304	1.442
BETA	4.3649	3.7218	5.0078

Fig. 7

24-hour Absolute Forecast Errors for A







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KURTOSIS	13.344	7.8431

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0056371	0.0027531
BETA	0.0027531	0.0013513

PERCENTILES	SAMPLE	FITTED
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10	0.1	0.087208
25	0.2	0.21475
50	0.4	0.45654
75	0.8	0.84681
90	1.4	1.3397
95	1.8	1.7053

GOODNESS OF FIT

CHI-SQUARE	2.6348[illegible]
DEG FREED	1.0000E0
SIGNIF	8.0540E-6
KOLM-SMIRN	1.2514E-1
SIGNIF	2.1378E-6
CRAMER-V M	1.2797E0
SIGNIF	< .01
ANDER-DARL	8.4172E0
SIGNIF	< .01

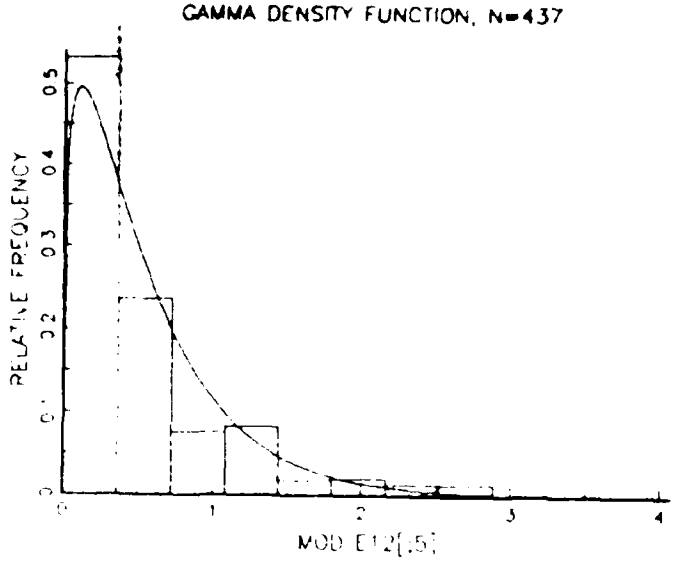
*S, AD AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

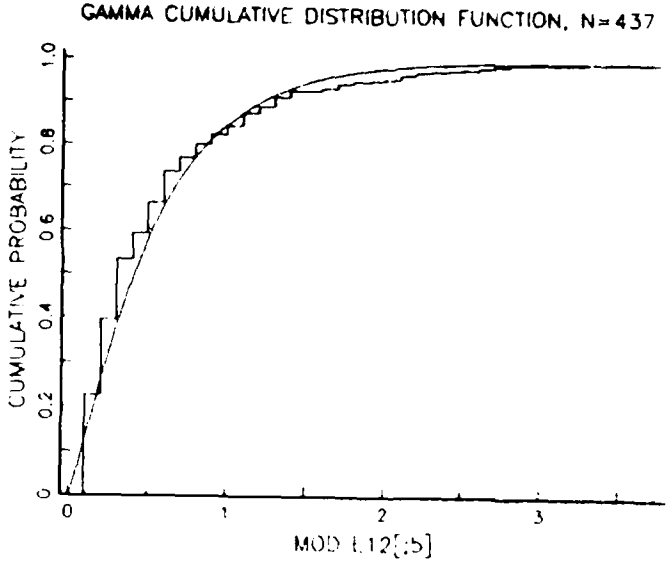
0.95 CONFIDENCE INTERVALS

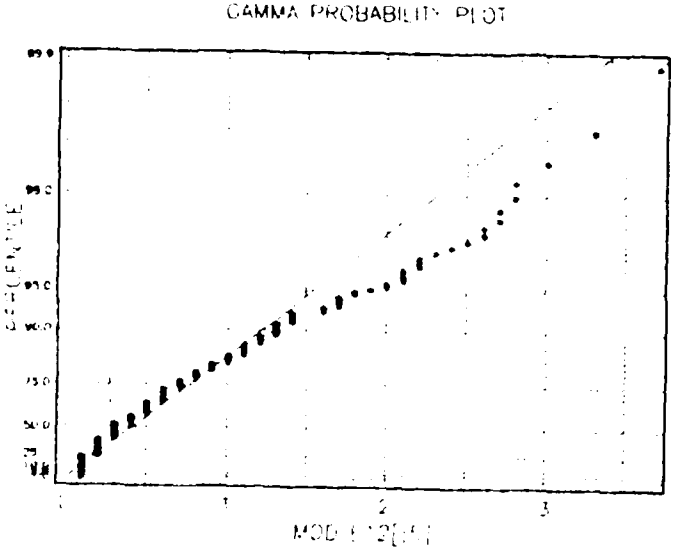
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.2389	1.0817	1.3961
BETA	0.49016	0.4231	0.56723

Fig. 6

12-hour Absolute Forecast Errors for Y_o







GAMMA DISTRIBUTION

X: MOD E12[,5]
SELECTION: ALL
LABEL: MOD E12[,5]
SAMPLE SIZE: 437
MINIMUM: 100
MAXIMUM: 3.700
CENSORING: NONE
EST METHOD: MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	0.554	0.554
STD DEV	0.59180	0.49884
SKEWNESS	2.1844	1.8017
KURTOSIS	8.7585	7.8885

PERCENTILES	SAMPLE	FITTED
5	0.1	0.045415
10	0.1	0.087979
25	0.2	0.19318
50	0.3	0.41548
75	0.7	0.78489
90	1.3	1.2314
95	1.9	1.5478

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0056804	0.0027424
BETA	0.0027424	0.0011101

GOODNESS OF FIT

CHI-SQUARE	3.1788[illegible]
DEG. FREED.	4.00000
SIGNIF	5.0.394[illegible]
KOLM-SMIRN	1.827[illegible]
SIGNIF	3.5103E-9
CRAMER-V-M	1.7187[illegible]
SIGNIF	< .01
ANDER-DARL	1.0886[illegible]
SIGNIF	< .01

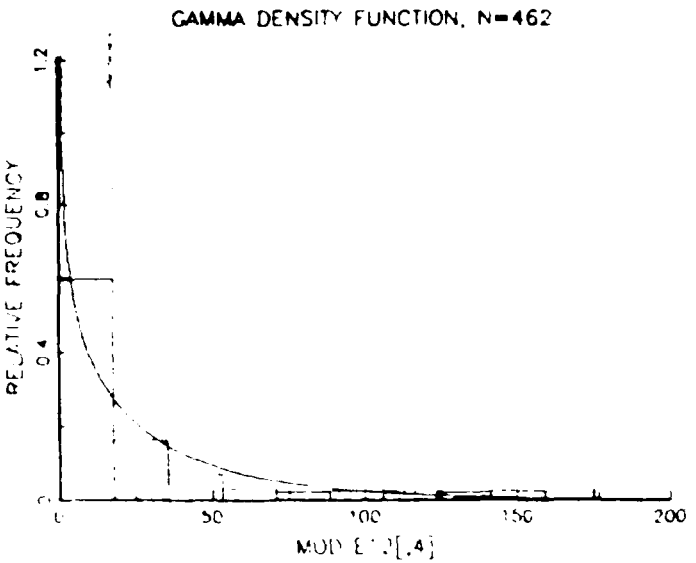
KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

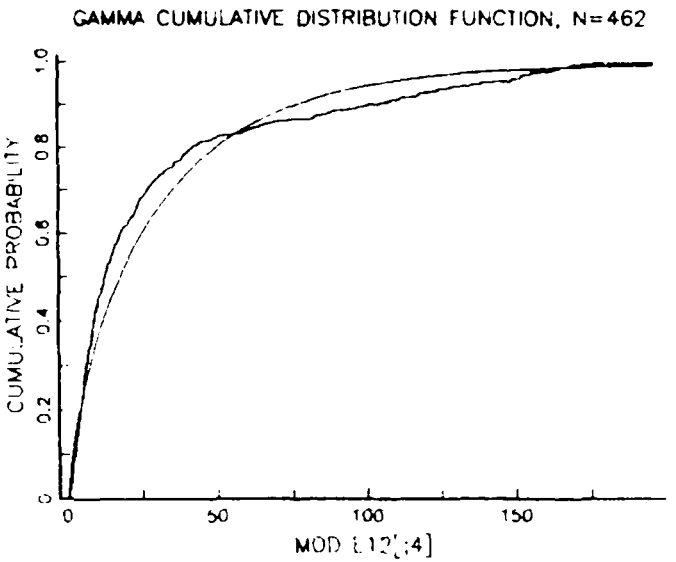
0.90 CONFIDENCE INTERVALS

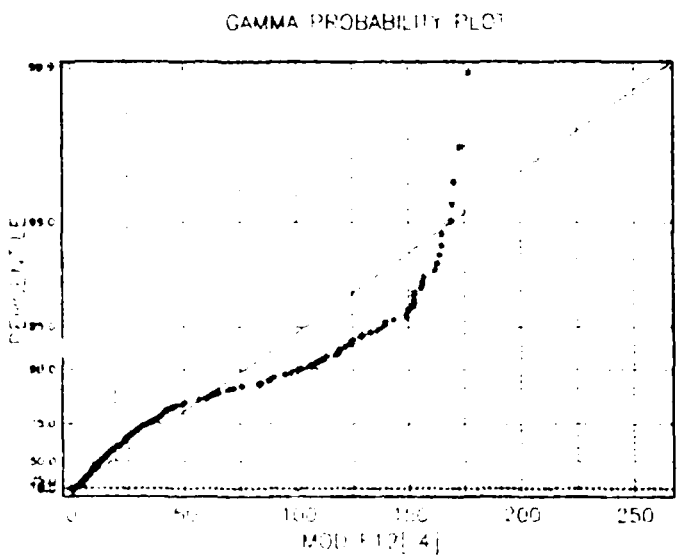
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.2329	1.0882	1.379[illegible]
BETA	0.44834	0.38376	0.51493

Fig. 5

12-hour Absolute Forecast Errors for X_c







GAMMA DISTRIBUTION

X	MOD E12[,4]
SELECTION	ALL
LABEL	MOD E12[,4]
SAMPLE SIZE	462
MINIMUM	100
MAXIMUM	178.700
CENSORING	NONE
EST. METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	30.345	30.345
STD DEV.	41.413	36.518
SKEWNESS	1.9813	2.3838
KURTOSIS	5.8002	11.584

PERCENTILES	SAMPLE	FITTED
5.	1.2	0.92771
10.	2.2	1.4348
25.	5.2	5.808
50.	12.3	17.838
75.	33.3	41.975
90.	100.5	78.22
95.	137.8	103.39

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0015322	0.095384
BETA	0.086384	11.796

GOODNESS OF FIT

CHI-SQUARE	6.7857E1
DFG FREED	7.0000E0
SIGNIF	2.5137E-10
KOLM-SMIRN	1.0191E-1
SIGNIF	1.3804E-4
CRAMER-V M	1.5471E0
SIGNIF	< .01
ANDER-DARL	8.5364E0
SIGNIF	< .01

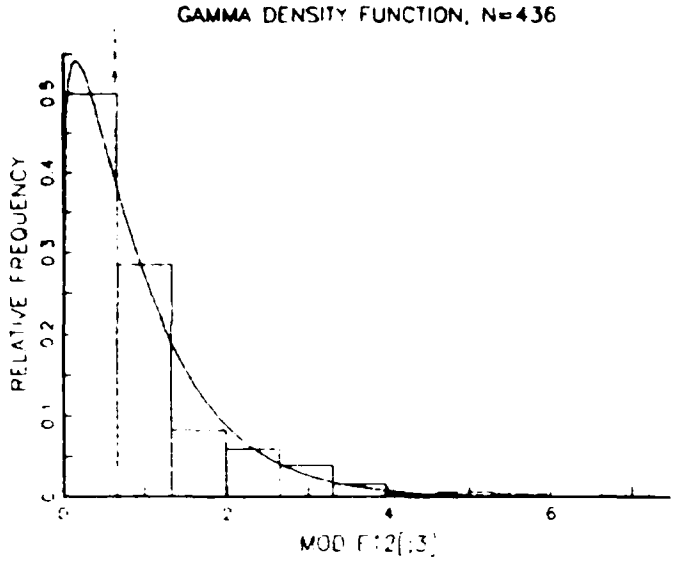
KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

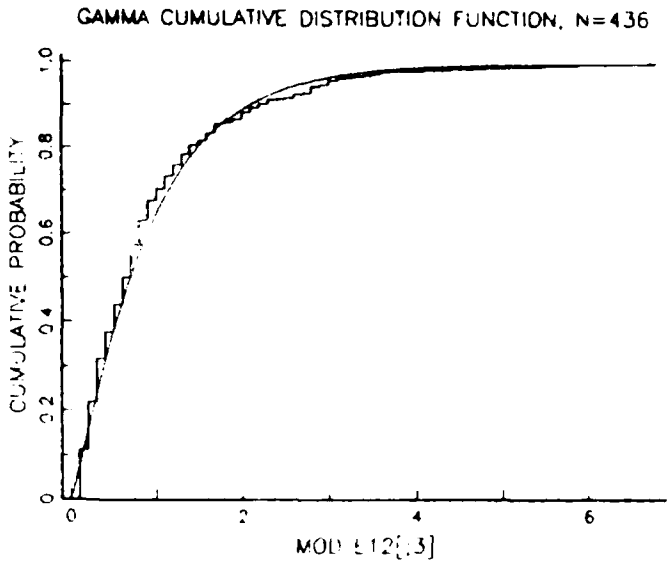
0.95 CONFIDENCE INTERVALS

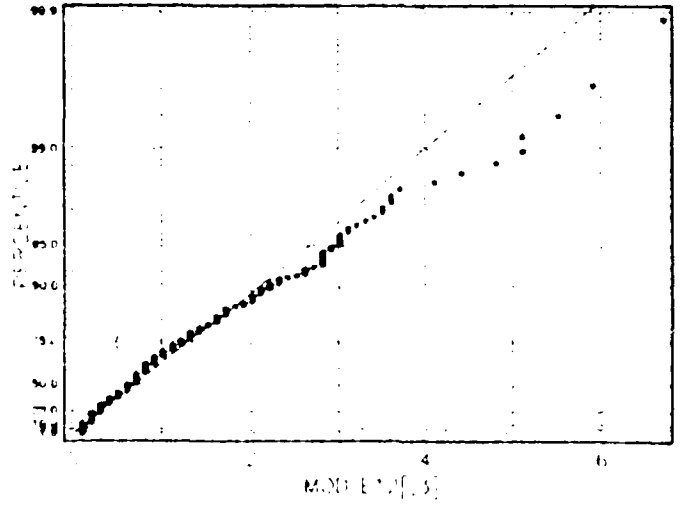
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	0.88815	0.62141	0.77488
BETA	43.485	38.732	80.199

Fig. 4

12-hour Absolute Forecast Errors for







GAMMA DISTRIBUTION

X	MOD F12[,3]
SELECTION	ALL
LABEL	MOD F12[,3]
SAMPLE SIZE	436
MINIMUM	100
MAXIMUM	6.700
CENSORING	NONE
EST METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	0.84541	0.84541
STD DEV	0.98537	0.86447
SKEWNESS	2.7505	1.8288
KURTOSIS	9.5439	8.0188

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0052884	-0.0034753
BETA	-0.0034753	0.0034995

PERCENTILES	SAMPLE	FITTED
5	0.1	0.072888
10	0.1	0.13474
25	0.3	0.32138
50	0.6	0.66887
75	1.2	1.3065
90	2.2	2.0829
95	3	2.6803

GOODNESS OF FIT

CHI SQUARE	11.882
DEG FREED	4
SIGNIF	0.022003
KOLM-SMIRN	0.039078
SIGNIF	0.0048023
CRAMER-V-M	0.58408
SIGNIF	< .05
ANDER-DARL	3.8813
SIGNIF	< .01

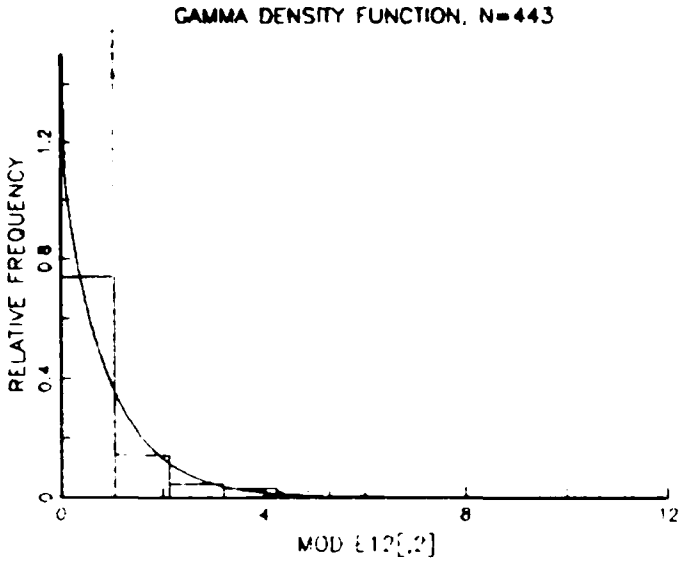
*S, AD AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

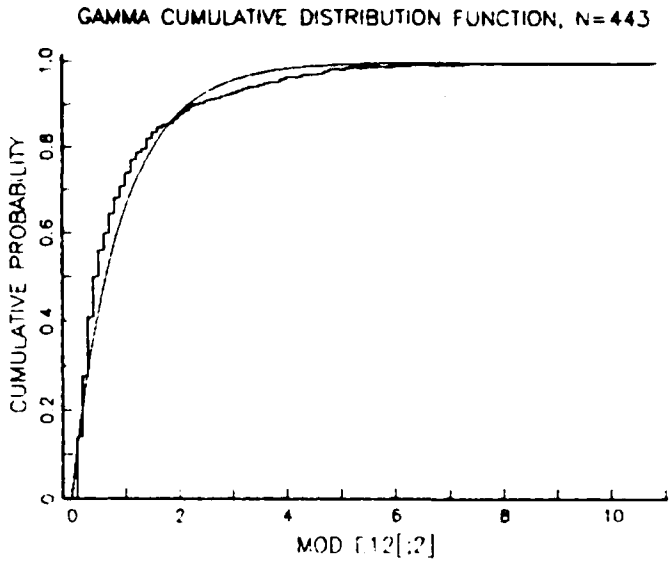
0.95 CONFIDENCE INTERVALS

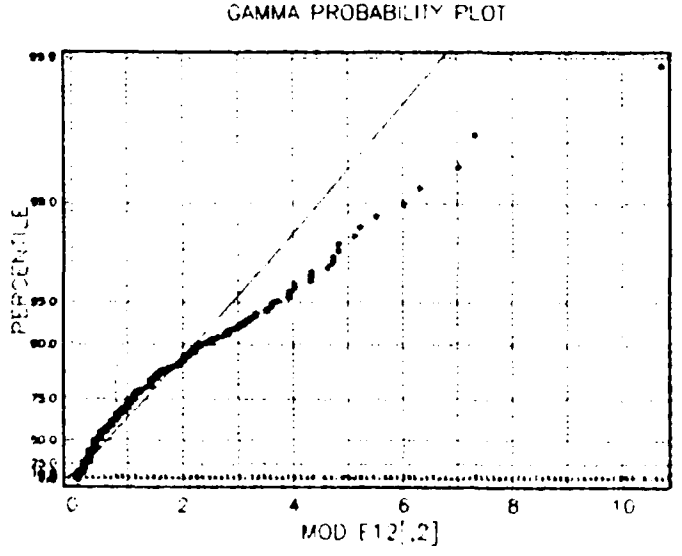
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.196	1.0539	1.3382
BETA	0.70848	0.67456	0.90836

Fig. 3

12-hour Absolute Forecast Errors for R







GAMMA DISTRIBUTION

X : MOD E12[,2]
SELECTION : ALL
LABEL : MOD E12[,2]
SAMPLE SIZE : 443
MINIMUM : .100
MAXIMUM : 10.700
CENSORING : NONE
EST METHOD : MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	0.93873	0.93873
STD DEV	1.2521	0.98565
SKEWNESS	3.0328	2.0967
KURTOSIS	15.855	9.3350

PERCENTILES	SAMPLE	FITTED
5	0.1	0.041864
10	0.1	0.089301
25	0.2	0.25539
50	0.4	0.63703
75	1.1	1.3079
90	2.3	2.193
95	3.6	2.8704

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.005113	-0.0037818
BETA	-0.0037818	0.0057648

GOODNESS OF FIT

CHI-SQUARE	2.8348E-1
DEG FREED	2.0000E 0
SIGNIF	8.9207E-1
KOLM-SMIRN	1.4348E-1
SIGNIF	2.4088E-0
CRAMER-V M	2.0538E 0
SIGNIF	< .01
ANDER-DARL	1.1824E1
SIGNIF	< .01

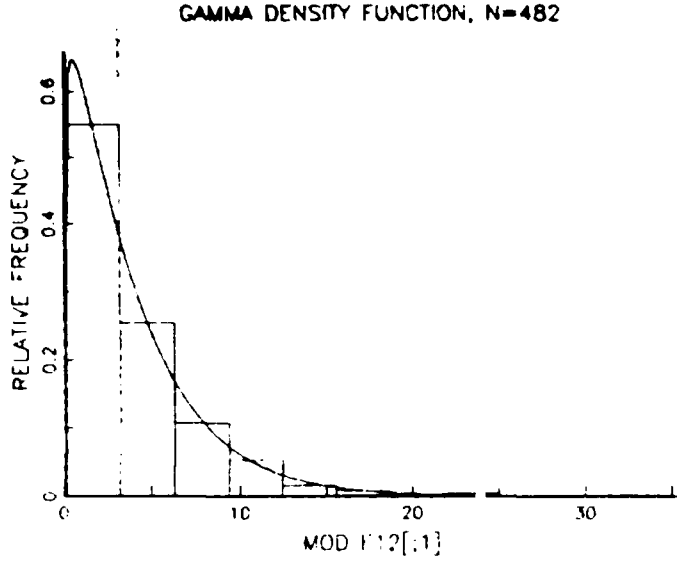
NO. AD. AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

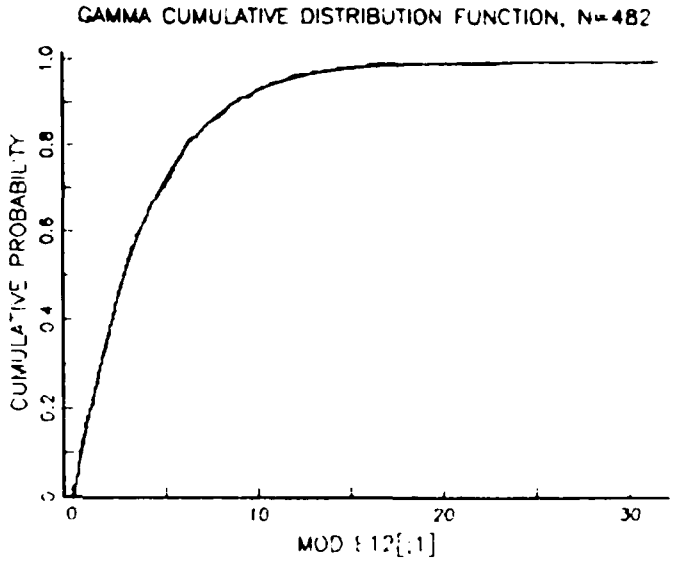
0.95 CONFIDENCE INTERVALS

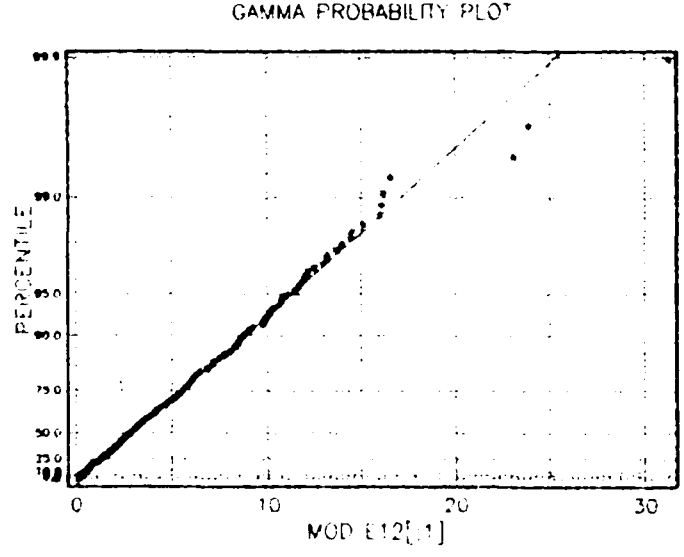
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	0.94703	0.83780	1.0564
BETA	0.99279	0.84345	1.1411

Fig. 2

12-hour Absolute Forecast Errors for







GAMMA DISTRIBUTION

X	MOD E12[,1]
SELECTION	ALL
LABEL	MOD E12[,1]
SAMPLE SIZE	482
MINIMUM	100
MAXIMUM	31.700
CENSORING	NONE
EST. METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	3.9129	3.9129
STD DEV	3.783	3.7059
SKEWNESS	2.1835	1.8842
KURTOSIS	11.908	8.3871

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0040824	-0.012853
BETA	-0.012853	0.083383

PERCENTILES	SAMPLE	FITTED
5.	0.3	0.75978
10.	0.4	0.48852
25.	1.3	1.2801
50.	2.8	2.8745
75.	5.5	5.4167
90.	8.7	8.7717
95	11	11.282

GOODNESS OF FIT

CHI-SQUARE	1.2134
DEG FREED	4
SIGNIF	0.87588
KOLM-SMIRN	0.020362
SIGNIF	0.83793
CRAMER-V M	0.035684
SIGNIF	> .15
ANDER-DARL	0.35893
SIGNIF	> .15

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

95% CONFIDENCE INTERVALS

PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.1149	0.88958	1.2401
BETA	3.5094	3.0183	4.0035

Fig. 1

12-hour Absolute Forecast Errors for A

REFERENCES

[1] Tsui, T. L. and Brody, L. R., "Objective Storm Tracking System", Preprint: Proceedings of the 9th Conference on Weather Forecasting & Analysis, Seattle, WA, June 28-July 1, 1982.

[2] Harr, P. A., Brody, L. R. and Tsui, T. L., "Verification Statistics of the Naval Operational Global Atmospheric Prediction System Tailored For The Field Forecaster", Extended Abstracts: Sixth Conference on Numerical Weather Prediction, Omaha, NE, June 6-9, 1983.

[3] Harr, P. A., Tsui, T. L. and Brody, L. R., "Model Verification Statistics Tailored For The Field Forecaster", Preprints: 8th Conference on Probability and Statistics in Atmospheric Sciences, Hot Spring, Arkansas, 1983.

The overall conclusion is that the incorporation of the SEIS and VTP methodology within the NOGAPS model has improved the storm tracking capability of NOGAPS and the elliptic representation of storms provides a good means of providing synoptic level error statistics to the field forecasters.

We propose the following topics for further study and research:

1. Determine the most appropriate probability distributions to describe the probabilistic behavior of the forecast errors. The indications are that the Weibull family may provide a good fit to the absolute error data.

2. Develop procedures to generate uncertainty contours/ confidence regions around the forecasted elliptic representations of a storm based on the probability distributions of the forecast errors.

3. Examine more data to determine the functional relationship (if it exists) between the forecasted and verification values of the elliptic parameters. Different stratification schemes for the storm data such as by geographic regions and by climatic seasons could lead to the identification of sources of systematic errors and the means of remediation.

4. Conclusions and Recommendations

This study has demonstrated that the NOGAPS model performs exceedingly well in forecasting five of the six parameters of the elliptic representation of a storm. The maximum mean absolute error in forecasting the amplitude A is 8.38 (Table 2) which is less than 1% of the verification values that range between 900 and 1,000; the maximum standard deviation of these errors in 6.92. Similar positive statements apply to the errors in forecasting ε, R, X_o, Y_o as can be seen from Tables 1 and 2 and the single high mode close to zero in the histograms (Figures 1-18) of absolute errors.

The autocorrelations (Table 3) between the errors in successive forecasts of any of the six parameters indicate that these errors may, for all practical purposes, be treated as independent. Similarly, for each forecast period, the errors in forecasting the parameters A, ε, R, α, X_o, Y_o appear to be independent (Table 4). What this implies is that a large error in forecasting a parameter may not have a lasting effect on other forecasts nor will it have a carry over effect on forecasting the other parameters.

Even at the individual storm level, the mean forecast errors and their standard deviations are quite small; once again the exception is the parameter α. Scatter plots of the forecasted values versus the verification values indicated a linear relationship between the two sets, in several cases. Regression analyses to fit straight lines to the data confirmed this observation (Table 6 and Figures 19-30). When the data was stratified according to the forecasts period, e.g., all 12 hour forecasts are treated as one group, and a separate regression analysis performed for each group the lienar relationship was accentuated (Table 7).

TABLE 7

ESTIMATED REGRESSION PARAMETERS FOR INDIVIDUAL FORECAST PERIOD

Storm No.	Forecast Period	A			X_o			Y_o		
		Intercept	Slope	Correlation	Intercept	Slope	Correlation	Intercept	Slope	Correlation
5	12	275.3	0.72	0.77	3.4	0.81	0.80	10.6	0.68	0.83
	24	476.2	0.52	0.72	7.4	0.56	0.78	6.0	0.83	0.96
	36	748.6	0.24	0.37	10.1	0.40	0.82	12.6	0.64	0.85
	48	1062.5	-0.08	-0.09	12.7	0.26	0.66	19.0	0.45	0.60
	60	1235.6	-0.25	-0.24	13.4	0.23	0.72	22.5	0.34	0.61
13	12	454.6	0.54	0.55	-2.0	1.11	0.96	-0.1	0.99	0.99
	24	572.5	0.43	0.52	3.3	0.81	0.94	-0.1	0.98	0.99
	36	740.7	0.26	0.39	6.4	0.63	0.78	0.1	0.97	0.99
	48	751.3	0.25	0.54	4.4	0.78	0.80	-1.4	1.01	0.99
	60	762.9	0.27	0.74	-1.0	0.99	0.78	-1.0	0.99	0.99
18	12	256.9	0.74	0.77	2.2	0.90	0.92	0.1	1.00	0.96
	24	489.0	0.50	0.49	3.7	0.81	0.81	2.8	0.93	0.93
	36	454.4	0.54	0.60	6.4	0.67	0.60	8.1	0.78	0.81
	48	616.6	0.37	0.45	14.9	0.25	0.22	14.8	0.57	0.66
	60	437.2	0.56	0.61	14.3	0.27	0.28	16.8	0.51	0.60
19	12	277.6	0.72	0.92	0.8	0.96	0.99	-0.7	1.02	0.99
	24	488.8	0.51	0.78	-0.8	1.05	0.99	-2.3	1.06	0.99
	36	646.1	0.35	0.54	-1.6	1.08	0.96	-1.9	1.06	0.94
	48	701.0	0.30	0.50	-4.3	1.20	0.94	-1.2	1.04	0.91
	60	819.9	0.18	0.38	-3.9	1.17	0.89	3.5	0.90	0.86

that can be made from the correlations in Table 7 is that the 12 and 24 hour forecasts, and to a lesser extent the 36 hour forecasts correspond well with the verification values; the efficiency of the forecasting scheme appears to drop after the 36 hour forecasts.

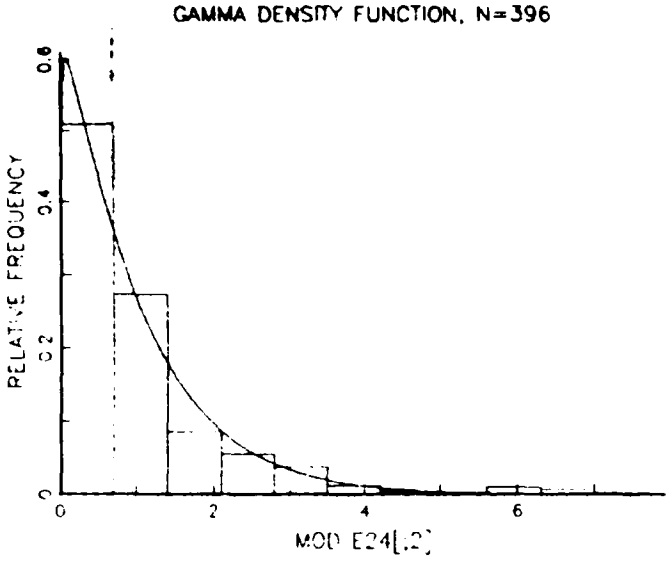
The regression analyses confirmed what was observed from the scatter plots, namely, a linear fit in many cases. If the functional relationship between the forecasted and verification values can be determined with good precision, corrective action can be taken to remove this source of systematic error in the forecasting scheme. However, the results in Table 6 do not lend themselves to the determination of the functional relationship. More data needs to be examined and different ways of stratifying the data such as by geographic regions and/or climatic seasons may prove to be profitable. Another possibility is to group the available records for a storm according to the forecast periods, i.e., all 12 hour forecasts as one group, all 24 hour forecasts as another group, etc. Of course, this scheme can only be applied to storms with large numbers of records. We tried this approach on 4 out of the 20 storms (storms 5, 13, 18 and 19, each with 60 or more records). The records for each storm were formed into five groups, one for each of the forecast periods and a separate regression analysis was performed for each group.

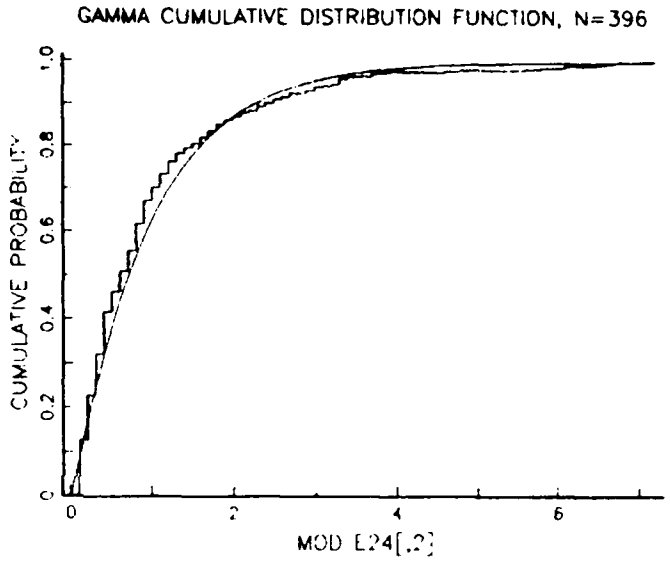
The estimated regression parameters in Table 7 reveal a much stronger linear relationship when the data is stratified according to the forecast period. Also, one can discern a definite pattern in the relationship between the forecasted and verification values of the storm's amplitude A. For the 12 hour forecasts, the relationship is linear with an intercept value of about 260 and slope .7; the intercept and slope values for the 48 hour forecasts are around 475 and .5 respectively. This is only an empirical observation and a more extensive study will be necessary to confirm this. Even though there is a strong correlation between the forecasted and verification values of X_o and Y_o, no pattern is evident in the estimates of the intercepts and slopes of the fitted lines. Another observation

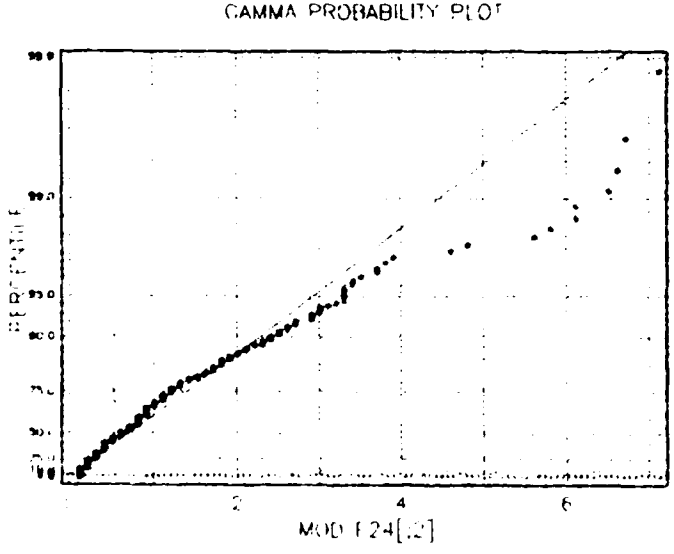
TABLE 6

ESTIMATED REGRESSION PARAMETERS

Storm No.	A			X_o				Y_o	
	Intercept	Slope	Correlation	Intercept	Slope	Correlation	Intercept	Slope	Correlation
1	212.9	0.79	0.91	12.1	0.45	0.55	28.8	0.25	0.51
2	630.2	0.37	0.90	15.5	0.25	0.64	38.9	-0.05	0.45
3	984.9	0.003	0.00	2.7	0.84	0.92	22.9	0.29	0.30
4	495.8	0.50	0.37	20.9	0.09	0.16	23.9	0.09	0.10
5	732.7	0.26	0.33	11.3	0.35	0.70	13.1	0.62	0.82
6	962.7	0.04	0.05	11.3	0.45	0.14	-7.3	1.12	0.73
7	589.3	0.41	0.75	2.0	0.88	0.75	15.5	0.61	0.95
8	357.8	0.64	0.64	7.5	0.68	0.87	12.4	0.57	0.86
9	1066.7	-0.08	0.09	8.5	0.63	0.85	8.7	0.69	0.91
10	714.8	0.28	0.28	-0.7	0.99	0.82	15.1	0.46	0.47
11	626.6	0.37	0.29	25.9	-0.20	-0.29	4.6	0.88	0.85
12	143.1	0.86	0.47	6.1	0.73	0.80	6.8	0.75	0.82
13	745.0	0.25	0.47	2.0	0.87	0.86	-0.2	0.98	0.99
14	-133.0	1.14	0.33	-4.0	1.19	0.48	10.7	0.59	0.89
15	446.2	0.55	0.67	7.9	0.60	-0.03	8.8	0.75	-0.29
16	640.4	0.35	0.79	-1.6	1.07	0.80	-0.6	1.01	0.60
17	349.5	0.65	0.09	4.1	0.81	0.32	0.4	0.97	0.38
18	812.9	0.13	0.59	8.4	0.52	0.60	0.3	0.99	0.81
19	261.3	0.74	0.57	22.5	-0.02	0.95	30.1	-0.09	0.93
20	959.5	0.04	0.31	10.1	0.50	0.91	27.9	0.24	0.97







GAMMA DISTRIBUTION

X	MOD E24[,2]
SELECTION	ALL
LABEL	MOD E24[,2]
SAMPLE SIZE	396
MINIMUM	100
MAXIMUM	* 100
CENSORING	NONE
EST METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	1.0018	1.0018
STD DEV	1.1581	0.8883
SKEWNESS	2.9635	* 9352
KURTOSIS	10.938	8.6174

PERCENTILES	SAMPLE	FITTED
5	0.1	0.080227
10	0.1	0.11874
25	0.3	0.30733
50	0.6	0.7121
75	1.2	1.3878
90	2.4	2.2895
95	3.3	2.9321

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0045271	-0.0039751
BETA	0.0039751	0.0055702

GOODNESS OF FIT

CHI SQUARE	7.46
DEG FREED	4
SIGNIF	0.11348
KOLM-SMIRN	0.10108
SIGNIF	0.00081154
CRAMER-V M	0.74817
SIGNIF	< .01
ANDER-DARL	4.0819
SIGNIF	< .01

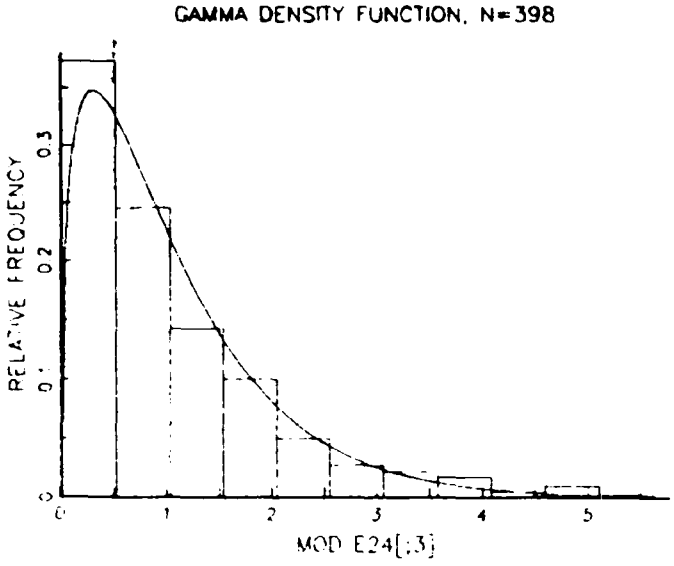
KS, AD, AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

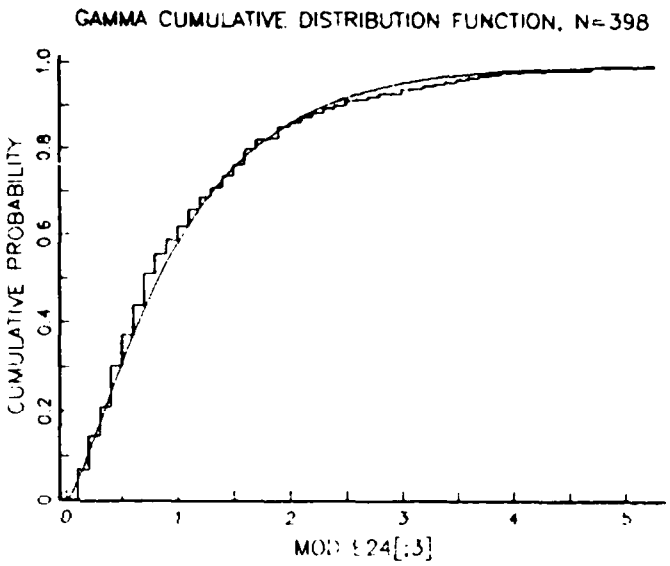
0.95 CONFIDENCE INTERVALS

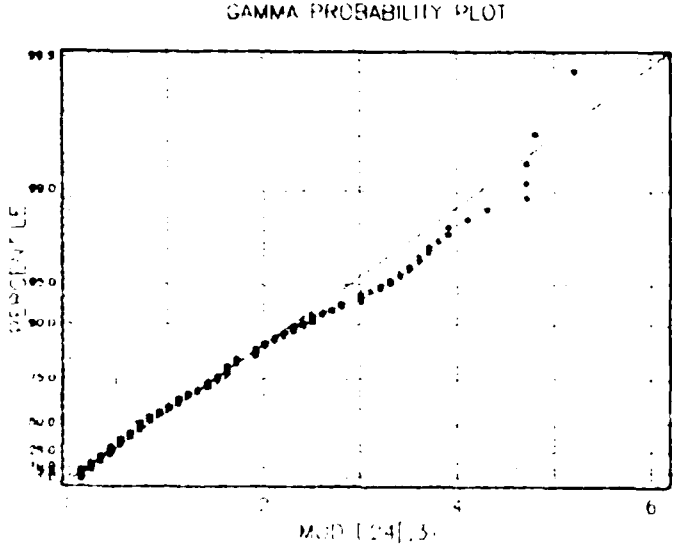
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.0881	0.93821	1.2
BETA	0.95789	0.79158	1.0842

Fig. 8

24-hour Absolute Forecast Errors for







GAMMA DISTRIBUTION

X	MOD E24[,3]
SELECTION	ALL
LABEL	MOD E24[,3]
SAMPLE SIZE	398
MINIMUM	.100
MAXIMUM	5.200
CENSORING	NONE
EST METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	1.0744	1.0744
STD DEV	0.8701	0.91313
SKEWNESS	1.84	1.8898
KURTOSIS	5.7184	7.3342

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0078094	0.0044318
BETA	0.0044318	0.0051778

PERCENTILES	SAMPLE	FITTED
5	0.1	0.10875
10	0.2	0.1888
25	0.4	0.43014
50	0.7	0.82982
75	1.6	1.4788
90	2.4	2.3832
95	3.5	2.8752

GOODNESS OF FIT

CHI-SQUARE	13.444
DEG FREED	6
SIGNIF	0.038601
KOLM-SMIRN	0.087344
SIGNIF	0.008058
CRAMER-V M^2	0.32883
SIGNIF	< .15
ANDER-DARL	2.0824
SIGNIF	< .10

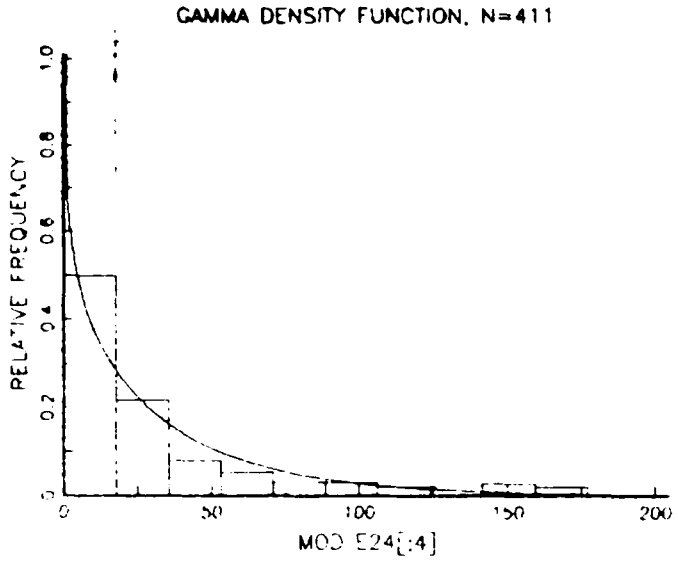
** KS, AD, AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

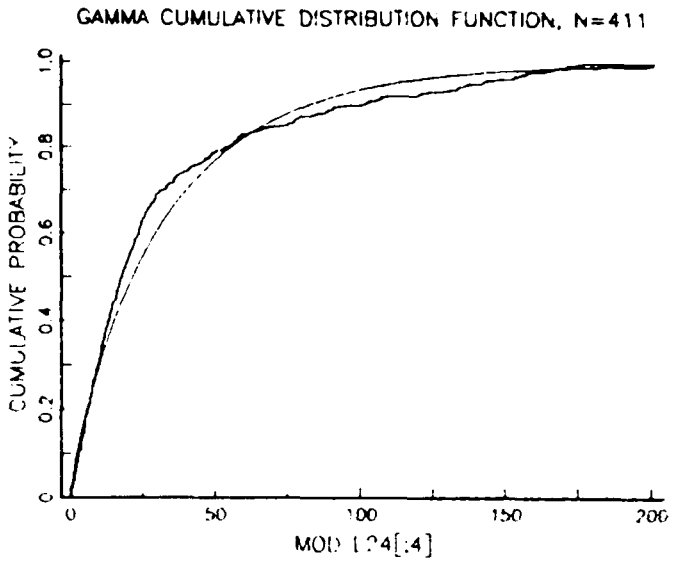
0.95 CONFIDENCE INTERVALS

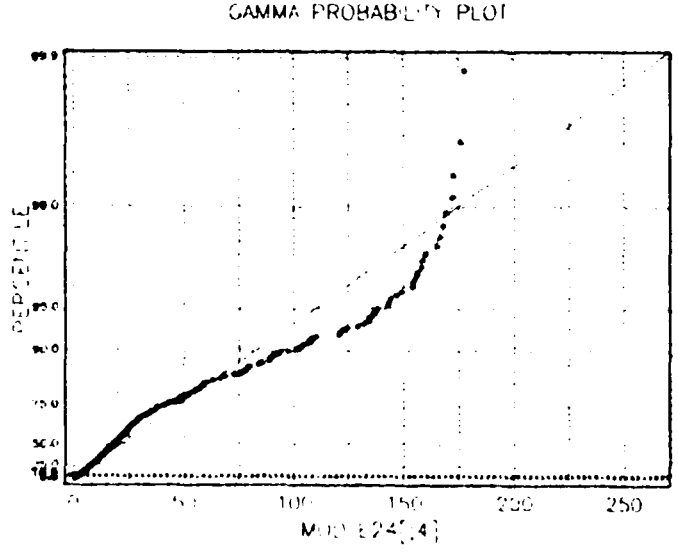
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.3843	1.21	1.5586
BETA	0.77609	0.65883	0.89335

Fig. 9

24-hour Absolute Forecast Errors for R







GAMMA DISTRIBUTION

X	MOD E24[:4]
SELECTION	ALL
LABEL	MOD E24[:4]
SAMPLE SIZE	411
MINIMUM	.100
MAXIMUM	177.000
CENSORING	NONE
EST METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	34.078	34.078
STD DEV	41.138	37.885
SKEWNESS	1.8484	2.2108
KURTOSIS	5.834	10.13

PERCENTILES	SAMPLE	FITTED
5	1.5	1.008
10	3	2.3809
25	7.8	7.8189
50	17.8	21.804
75	41.5	47.138
90	96.8	82.401
95	137.7	109.83

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0024387	0.17609
BETA	0.12609	11.683

GOODNESS OF FIT

CHI-SQUARE	3.9021E1
DF C PRED	7.000000
SIGNIF	3.1358E-6
KOLM-SMIRN	8.6234E-2
SIGNIF	3.3747E-3
CRAMER-V M	7.3095E-1
SIGNIF	< .005
ANDER DARL	3.992380
SIGNIF	< .01

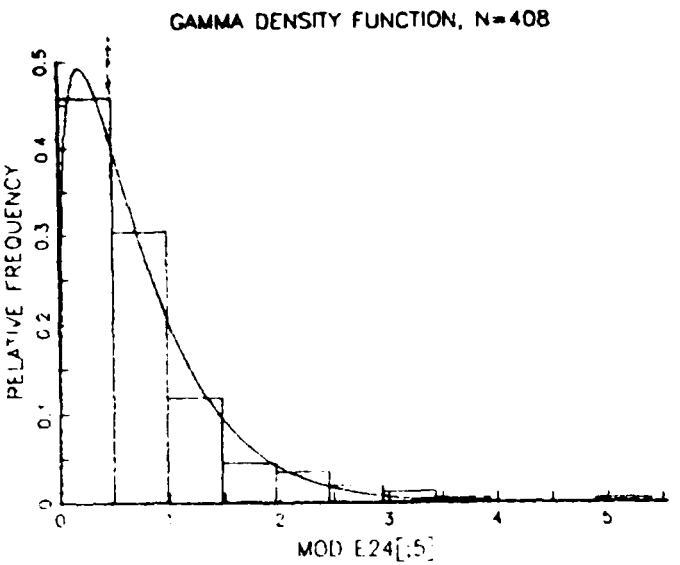
KS, AD AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

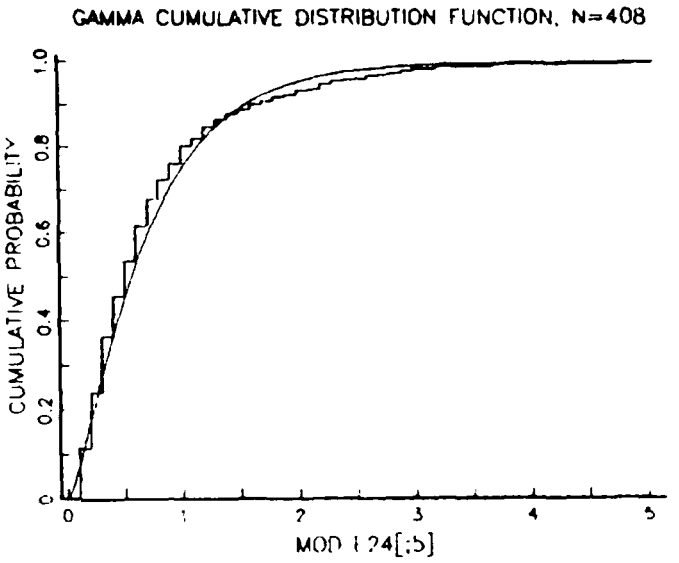
0.95 CONFIDENCE INTERVALS

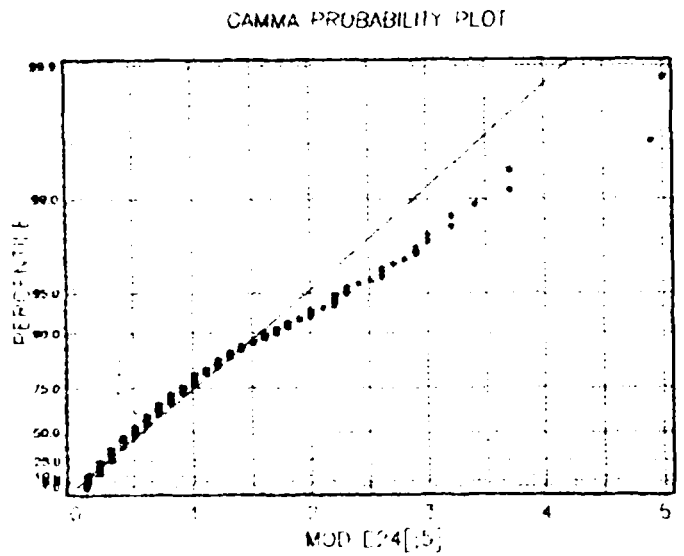
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	0.81651	0.72188	0.91534
BETA	41.631	34.994	48.299

Fig. 10

24-hour Absolute Forecast Errors for







GAMMA DISTRIBUTION

X	MOD E24[;5]
SELECTION	ALL
LABEL	MOD E24[;5]
SAMPLE SIZE	408
MINIMUM	100
MAXIMUM	5 000
CENSORING	NONE
EST. METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	0 73084	0 73084
STD DEV	0 73779	0 62478
SKEWNESS	2 3428	1 7089
KURTOSIS	10 101	7 3803

PERCENTILES	SAMPLE	FITTED
5	0 1	0 073232
10	0 1	0 1766
25	0 3	0 27673
50	0 5	0 58254
75	0 9	1 0048
90	1 7	1 5867
95	2 3	1 8824

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0 0175383	0 0029350
BETA	0 0029350	0 0018824

GOODNESS OF FIT

CHI-SQUARE	12 449
DEG FREED	4
SIGNIF	0 014301
KOLM-SMIRN	0 084887
SIGNIF	0 0013891
CRAMER-V M	0 76772
SIGNIF	< 01
ANDER-DARL	4 8047
SIGNIF	< 01

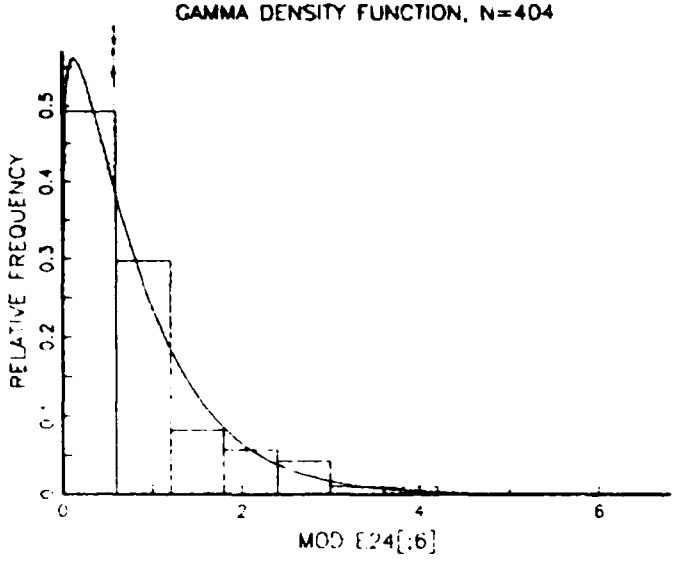
KS, AD, AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

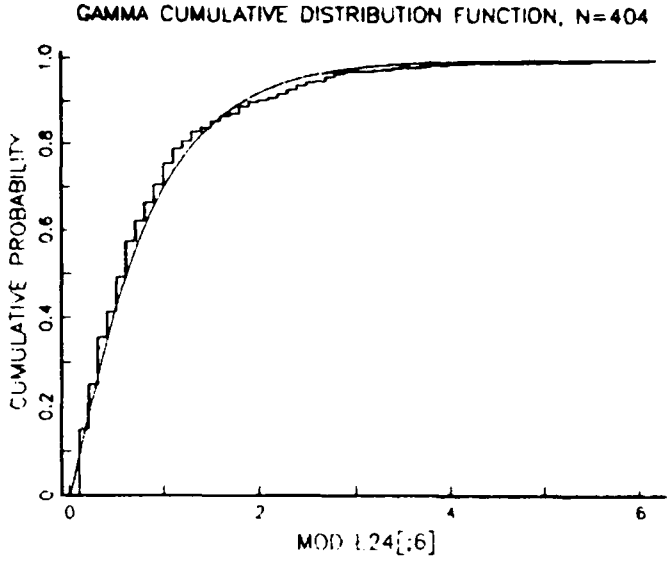
0 95 CONFIDENCE INTERVALS

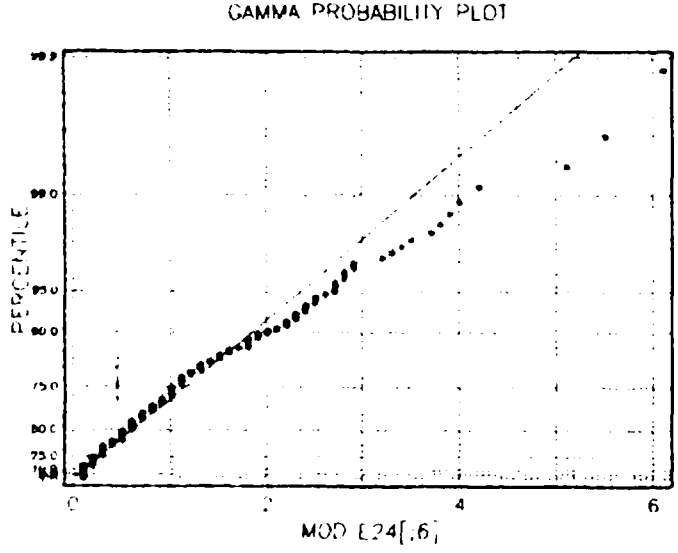
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1 3998	1 1995	1 54
BETA	0 0334	0 45371	0 61309

Fig. 11

24-hour Absolute Forecast Errors for X_o







GAMMA DISTRIBUTION

X	MOD E24[:6]
SELECTION	ALL
LABEL	MOD E24[.6]
SAMPLE SIZE	404
MINIMUM	100
MAXIMUM	8 100
CENSORING	NONE
EST METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	0 83317	0 83317
STD DEV	0 88053	0 70537
SKEWNESS	2 3356	1 8372
KURTOSIS	10 785	8 0832

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0 0095821	0 0033
BETA	0 0033	0 0029805

PERCENTILES	SAMPLE	FITTED
5	0 1	0 083003
10	0 1	0 17408
25	0 2	0 28098
50	0 6	0 614
75	1	1 1577
90	2	1 8387
95	2 7	2 3519

GOODNESS OF FIT

CHI-SQUARE	13 907
DEG FREED	4
SIGNIF	0 0075807
KOLM-SMIRN	0 089644
SIGNIF	0 0029978
CRAMER-V M	0 59778
SIGNIF	< 075
ANDER-DARL	4 4576
SIGNIF	< 01

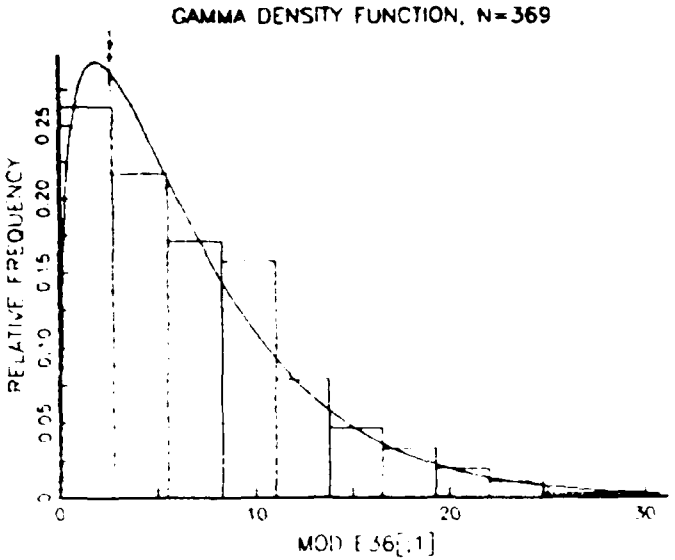
MS. AD. AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

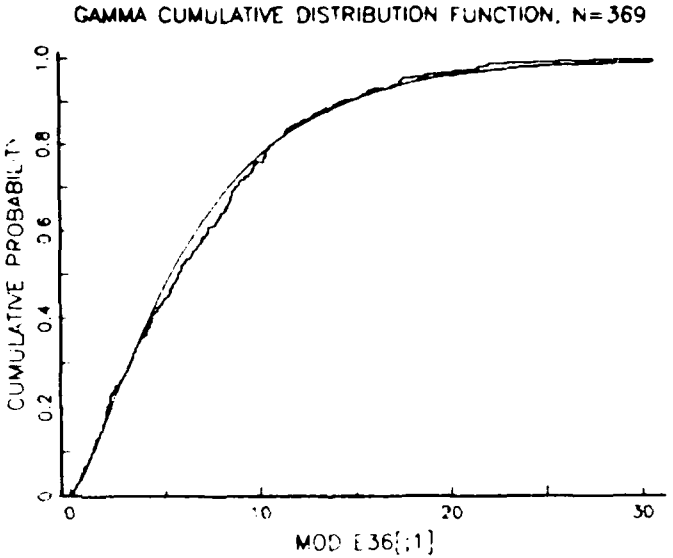
0 90 CONFIDENCE INTERVALS

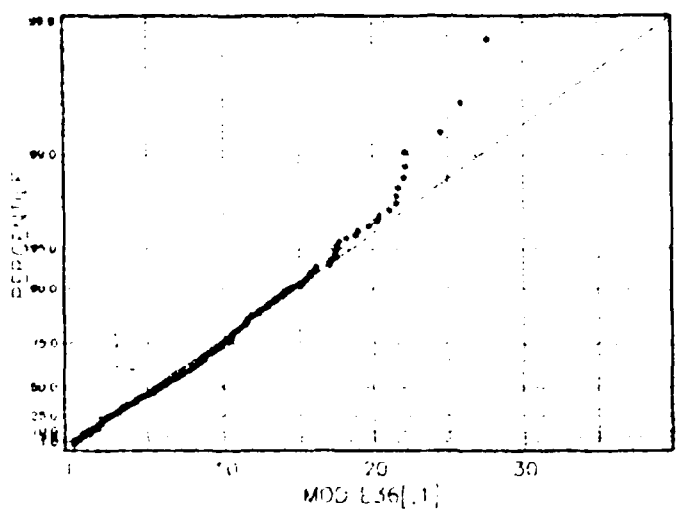
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1 185	1 0388	1 3312
BETA	0 70308	0 59588	0 81069

Fig. 12

24-hour Absolute Forecast Errors for Y_o







GAMMA DISTRIBUTION

X	MOD E36[,1]
SELECTION	ALL
LABEL	MOD E36[,1]
SAMPLE SIZE	369
MINIMUM	100
MAXIMUM	27.800
CENSORING	NONE
EST METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	8.881	8.881
STD DEV	5.3723	5.8838
SKEWNESS	1.0795	1.7047
KURTOSIS	3.9433	7.3587

PERCENTILES	SAMPLE	FITTED
5	2.6	2.6983
10	3.1	3.2009
25	5.2	5.2188
50	8.7	8.3099
75	11.8	11.4809
90	14.5	14.647
95	17.5	18.447

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0084331	-0.030584
BETA	-0.030584	0.10012

GOODNESS OF FIT

CHI-SQUARE	8.6881
DEG FREED	7
SIGNIF	0.19025
KOLM-SMIRN	0.050016
SIGNIF	0.31443
CRAMER-V M	0.1896
SIGNIF	> .15
ANDER-DARL	0.89964
SIGNIF	> .15

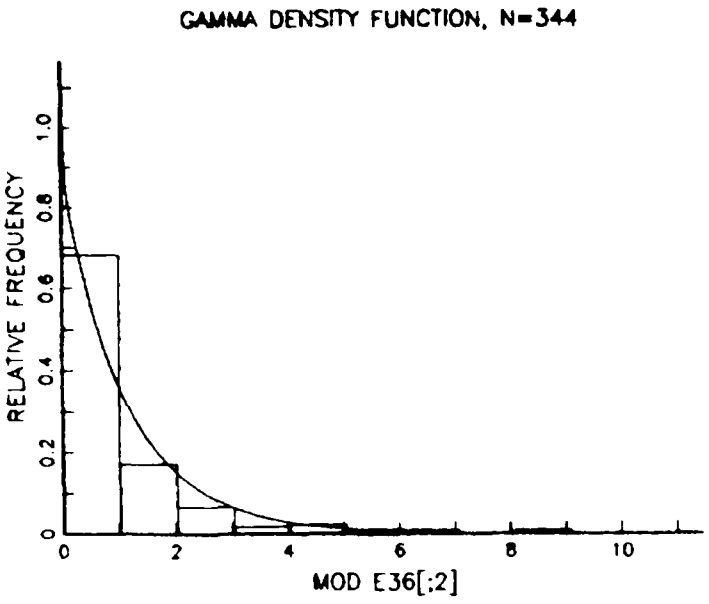
KS, AD, AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

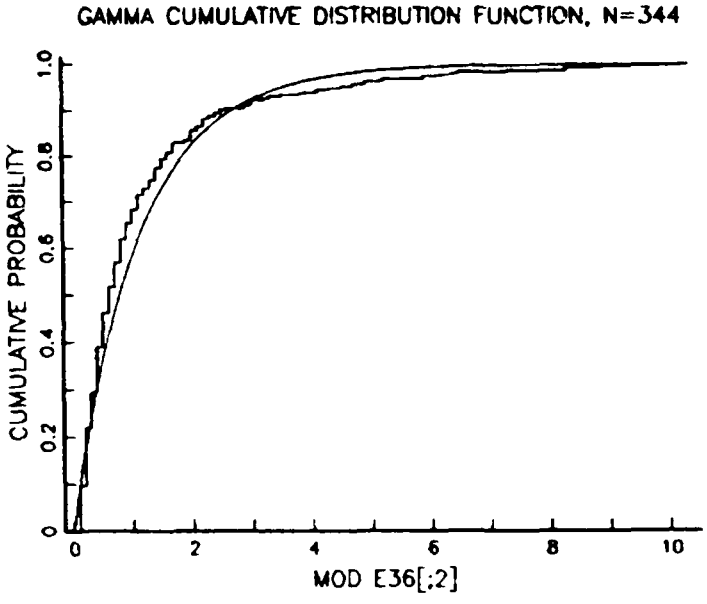
0.95 CONFIDENCE INTERVALS

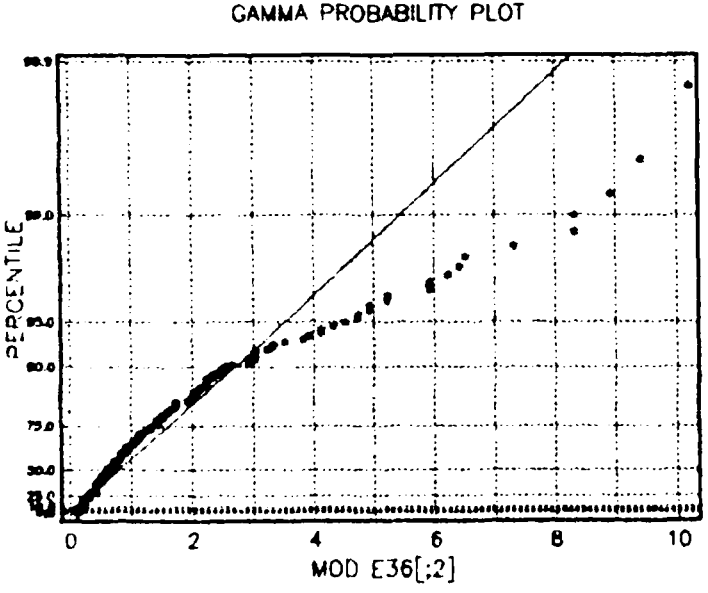
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.3772	1.1972	1.5872
BETA	4.9964	4.2719	5.7808

Fig. 13

36-hour Absolute Forecast Errors for A







GAMMA DISTRIBUTION

X	:	MOD E36[;2]
SELECTION	:	ALL
LABEL	:	MOD E36[;2]
SAMPLE SIZE	:	344
MINIMUM	:	.100
MAXIMUM	:	10.200
CENSORING	:	NONE
EST. METHOD	:	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	1.157	1.157
STD DEV	1.8400	1.176
SKEWNESS	3.014	2.0304
KURTOSIS	13.[illegible]	9.[illegible]

PERCENTILES	SAMPLE	FITTED
5:	0.1	0.[illegible]
10:	0.2	0.11[illegible]
25:	0.3	0.[illegible]
50:	0.6	0.7[illegible]
75:	1.4	1.[illegible]
90:	2.6	2.[illegible]
95:	4.8	3.5107

GOVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.[illegible]	[illegible]
BETA	[illegible]	[illegible]

GOODNESS OF FIT

CHI-SQUARE	24.240
DEG FREED	3
SIGNIF	[illegible]
KOLM-SMIRN	0.11[illegible]
SIGNIF	[illegible]
CRAMER-V M	1.176
SIGNIF	< .01
ANDER-DARL	7.[illegible]
SIGNIF	< .01

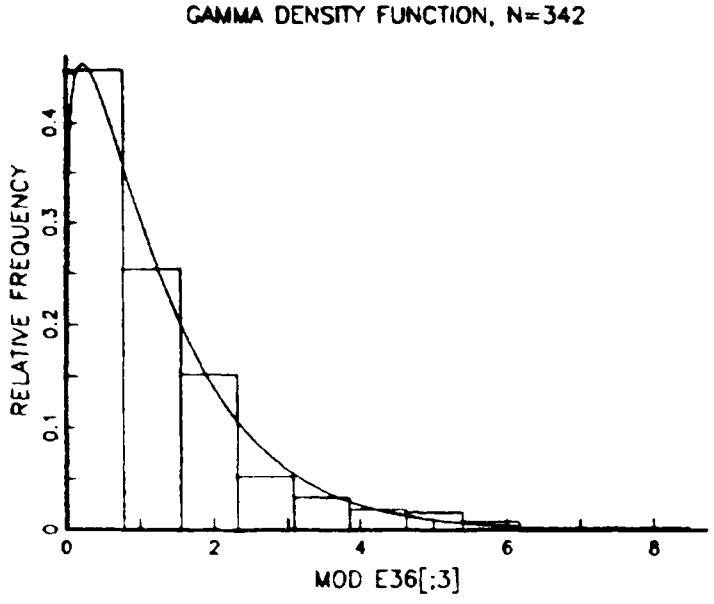
KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

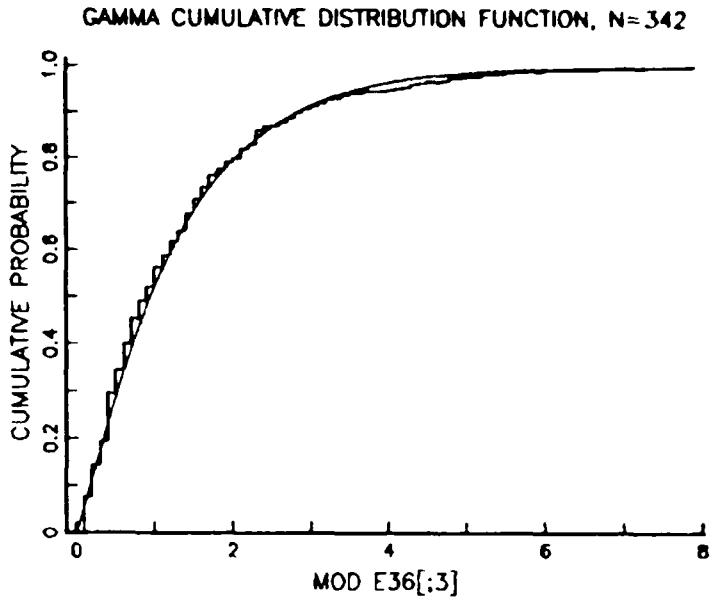
0.05 CONFIDENCE INTERVALS

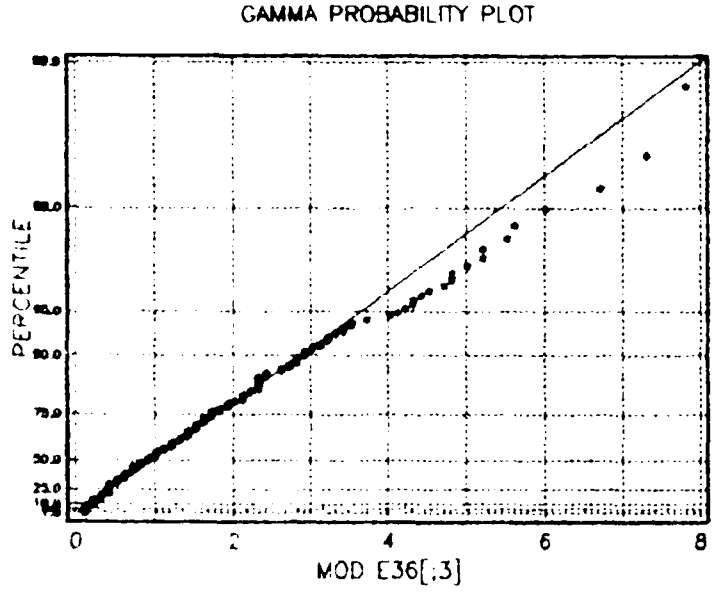
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	0.[illegible]	0.[illegible]	1.[illegible]
BETA	1.1[illegible]	0.[illegible]	1.[illegible]

Fig. 14

36-hour Absolute Forecast Errors for







GAMMA DISTRIBUTION

X : MOD E36[;3]
SELECTION : ALL
LABEL : MOD E36[;3]
SAMPLE SIZE: 342
MINIMUM : .100
MAXIMUM : 7.800
CENSORING : NONE
EST. METHOD: MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	1.2630	1.2630
STD DEV	1.2783	1.1771
SKEWNESS	1.8889	1.8186
KURTOSIS	7.8637	7.988

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.[illegible]	-0.008074
BETA	-0.008074	0.[illegible]

PERCENTILES	SAMPLE	FITTED
5:	0.1	0.10182
10:	0.2	0.18726
25:	0.4	0.44358
50:	0.8	0.88853
75:	1.7	1.7875
90:	2.9	2.9433
95:	4.1	3.888

GOODNESS OF FIT

CHI-SQUARE :	7.8373
DEG FREED:	5
SIGNIF :	0.18544
KOLM-SMIRN :	0.07
SIGNIF :	0.07005
CRAMER-V M :	0.23787
SIGNIF :	> .15
ANDER-DARL :	1.8888
SIGNIF :	< .15

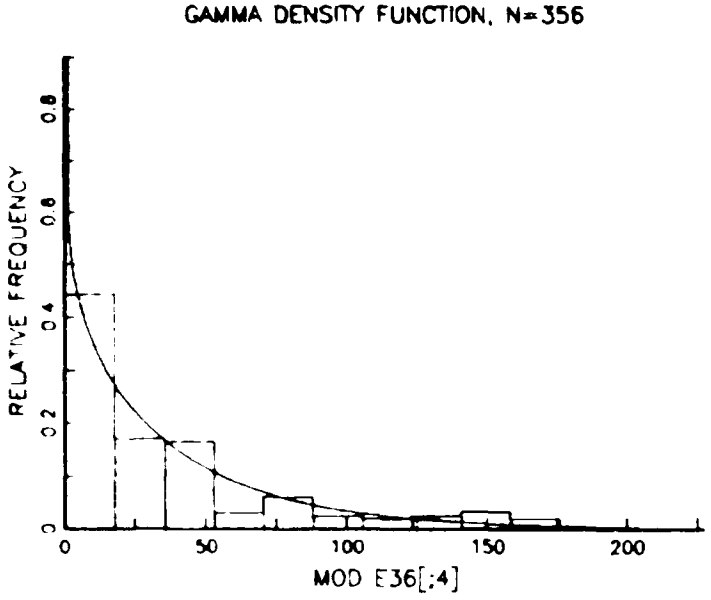
KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

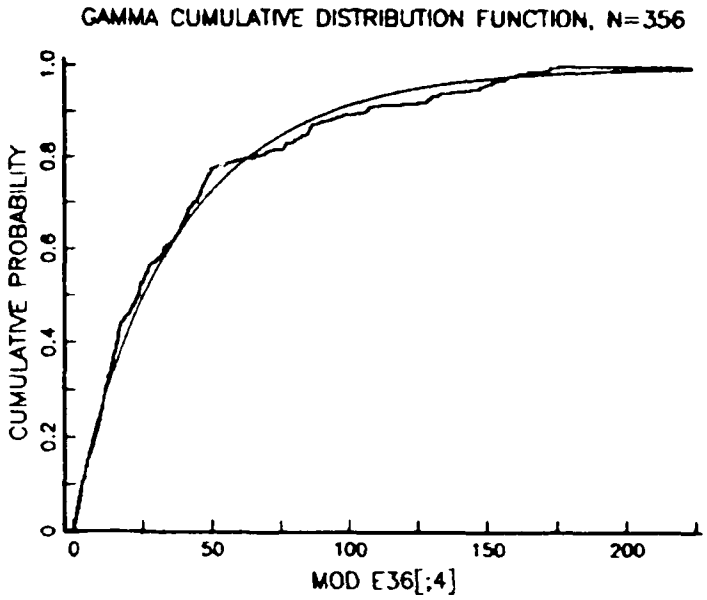
0.80 CONFIDENCE INTERVALS

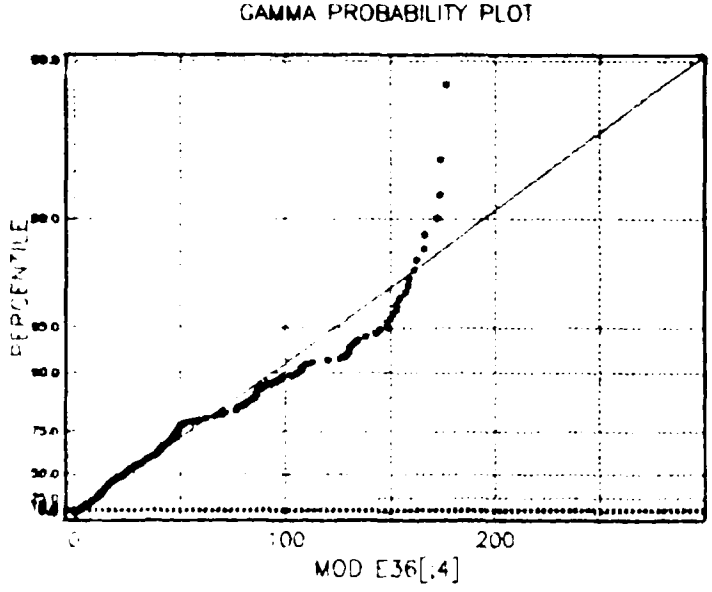
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.2082	1.0458	1.3705
BETA	1.0709	0.8938	1.2478

Fig. 15

36-hour Absolute Forecast Errors for R







GAMMA DISTRIBUTION

X	MOD E36[;4]
SELECTION	ALL
LABEL	MOD E36[;4]
SAMPLE SIZE	356
MINIMUM	.100
MAXIMUM	175.800
CENSORING	NONE
EST. METHOD	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	38.83	38.83
STD DEV	42.382	41.936
SKEWNESS	1.671	2.1394
KURTOSIS	4.6821	9.8948

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	9.0831308	-0.18488
BETA	-0.18488	15.402

PERCENTILES	SAMPLE	FITTED
5:	1.8	1.3183
10.	2.8	3.0121
25:	9.7	9.4343
50:	23	25.184
75:	47.8	53.778
90:	108.8	82.837
95.	147.5	122.85

GOODNESS OF FIT

CHI-SQUARE	4.161161
DEG FREED	7.0000E0
SIGNIF	1.411OE-6
KOLM-SMIRN	8.2160E-2
SIGNIF	1.2783E-1
CRAMER-V M	2.1130E-1
SIGNIF	> .15
ANDER-DARL	1.3329E0
SIGNIF	> .15

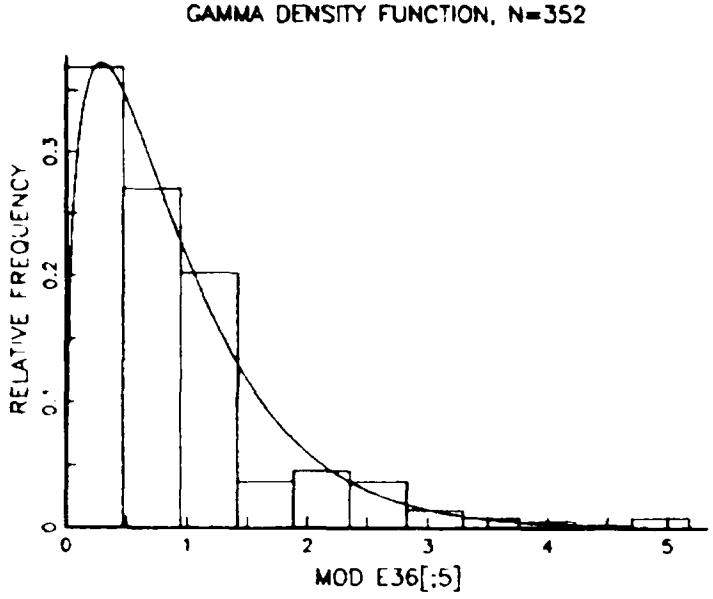
KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

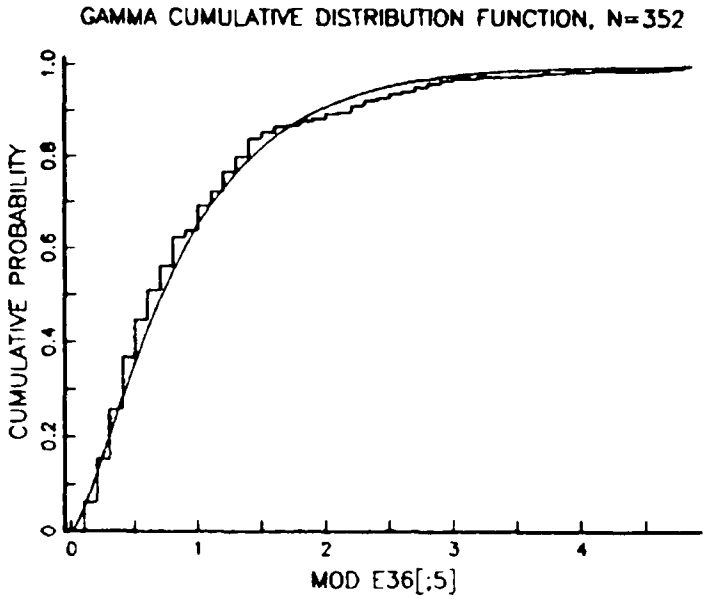
0.95 CONFIDENCE INTERVALS

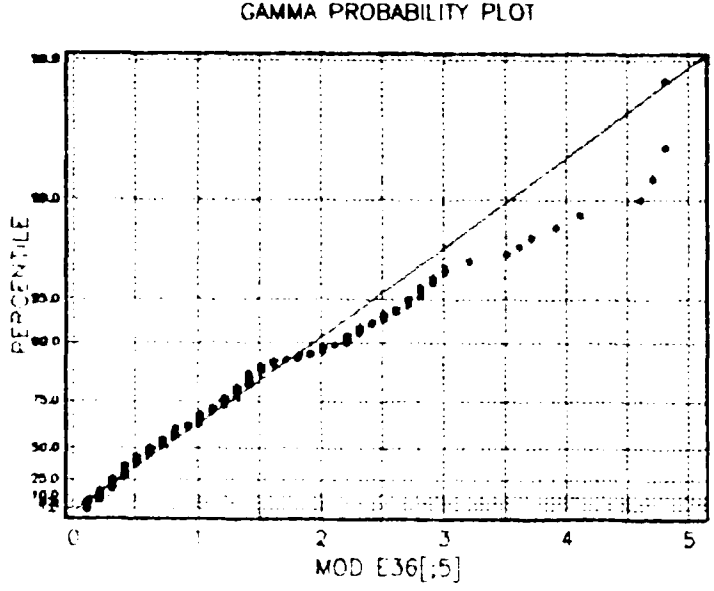
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	0.85778	0.74827	0.98729
BETA	45.998	37.578	82.962

Fig. 16

36-hour Absolute Forecast Errors for







GAMMA DISTRIBUTION

X	:	MOD E36[;5]
SELECTION	:	ALL
LABEL	:	MOD E36[;5]
SAMPLE SIZE	:	352
MINIMUM	:	.100
MAXIMUM	:	4.800
CENSORING	:	NONE
EST METHOD	:	MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	0.91847	0.91847
STD DEV	0.85813	0.79139
SKEWNESS	1.8858	1.658
KURTOSIS	7.8338	7.1233

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0088437	-0.0043132
BETA	-0.0043132	0.0029487

PERCENTILES	SAMPLE	FITTED
5:	0.1	0.10234
10:	0.2	0.17222
25:	0.3	0.36347
50:	0.6	0.71878
75:	1.2	1.2587
90:	2.3	1.8281
95:	2.7	2.4171

GOODNESS OF FIT

CHI-SQUARE	: 18.881
DEG FREED	: 5
SIGNIF	: 0.0027988
KOLM-SMIRN	: 0.080381
SIGNIF	: 0.0035187
CRAMER-V M	: 0.61113
SIGNIF	: < .05
ANDER-DARL	: 3.1377
SIGNIF	: < .025

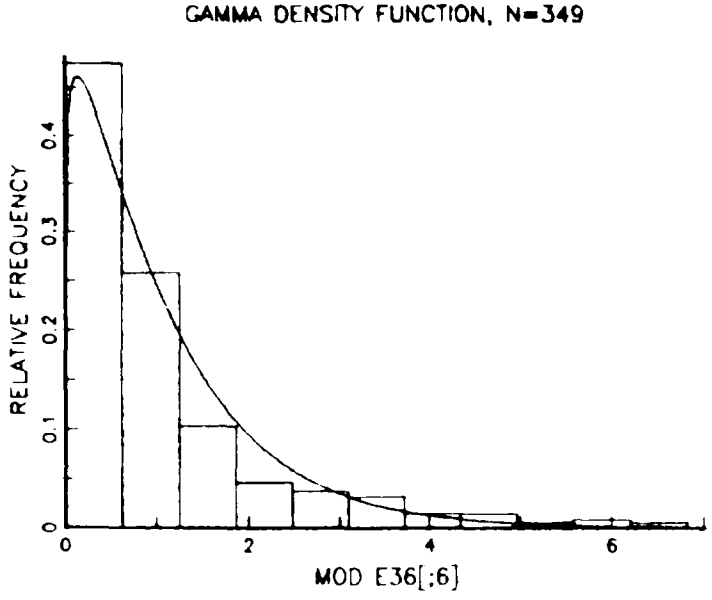
KS, AD, AND CV SIGNIF LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

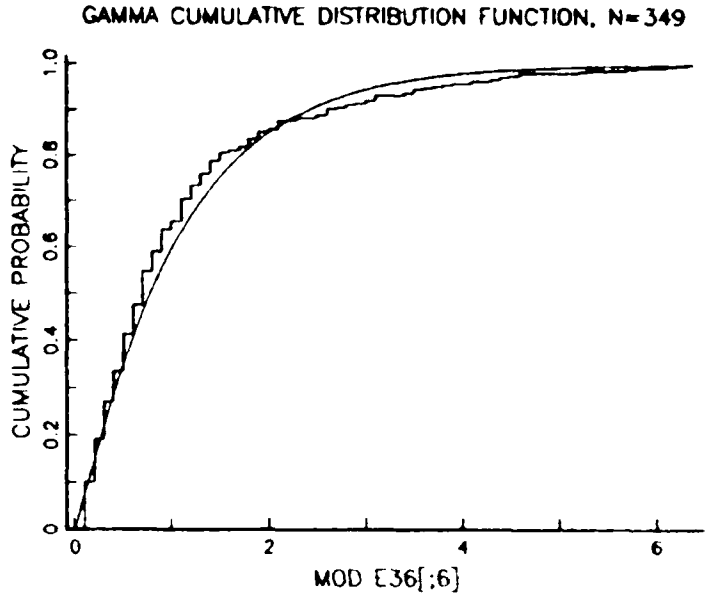
0.95 CONFIDENCE INTERVALS

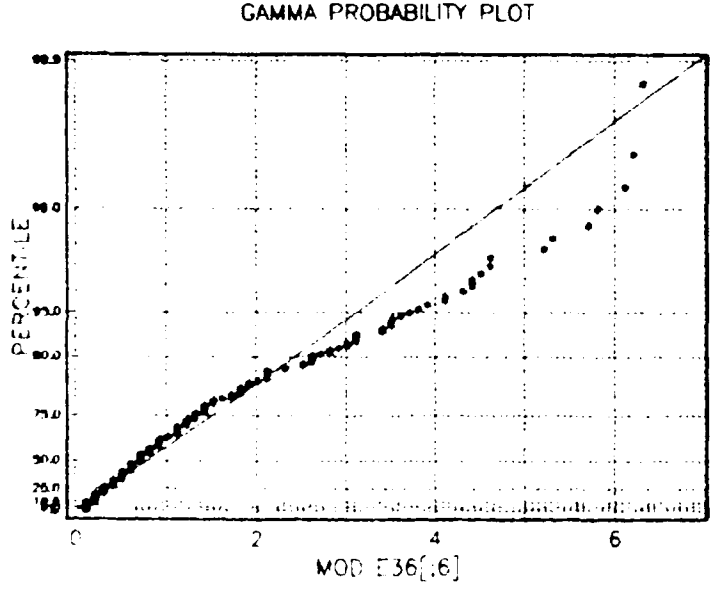
PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.4961	1.2367	1.8508
BETA	0.63118	0.53029	0.73208

Fig. 17

36-hour Absolute Forecast Errors for X_o







GAMMA DISTRIBUTION

X : MOD E36[;6]
SELECTION : ALL
LABEL : MOD E36[;6]
SAMPLE SIZE : 349
MINIMUM : .100
MAXIMUM : 8.300
CENSORING : NONE
EST. METHOD: MAXIMUM LIKELIHOOD

	SAMPLE	FITTED
MEAN	1.0817	1.0817
STD DEV.	1.1728	1.0146
SKEWNESS:	2.1488	1.8785
KURTOSIS:	7.8878	8.282

COVARIANCE MATRIX OF PARAMETER ESTIMATES

	ALPHA	BETA
ALPHA	0.0058731	-0.0048232
BETA	-0.0048232	0.0084142

PERCENTILES	SAMPLE	FITTED
5:	0.1	0.074886
10:	0.1	0.1421
25:	0.3	0.35149
50:	0.7	0.78881
75:	1.3	1.4888
90:	2.4	2.4136
95:	3.7	3.0886

GOODNESS OF FIT

CHI-SQUARE :	17.885
DEG. FREED. :	6
SIGNIF :	0.0830836
KOLM-SMIRN :	0.088888
SIGNIF :	0.0070879
CRAMER-V M :	0.67273
SIGNIF :	< .05
ANDER-DARL :	3.783
SIGNIF :	< .025

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS

0.95 CONFIDENCE INTERVALS

PARAMETER	ESTIMATE	LOWER	UPPER
ALPHA	1.1358	0.8857	1.2882
BETA	0.95222	0.79522	1.1082

Fig. 18

36-hour Absolute Forecast Errors for Y_o

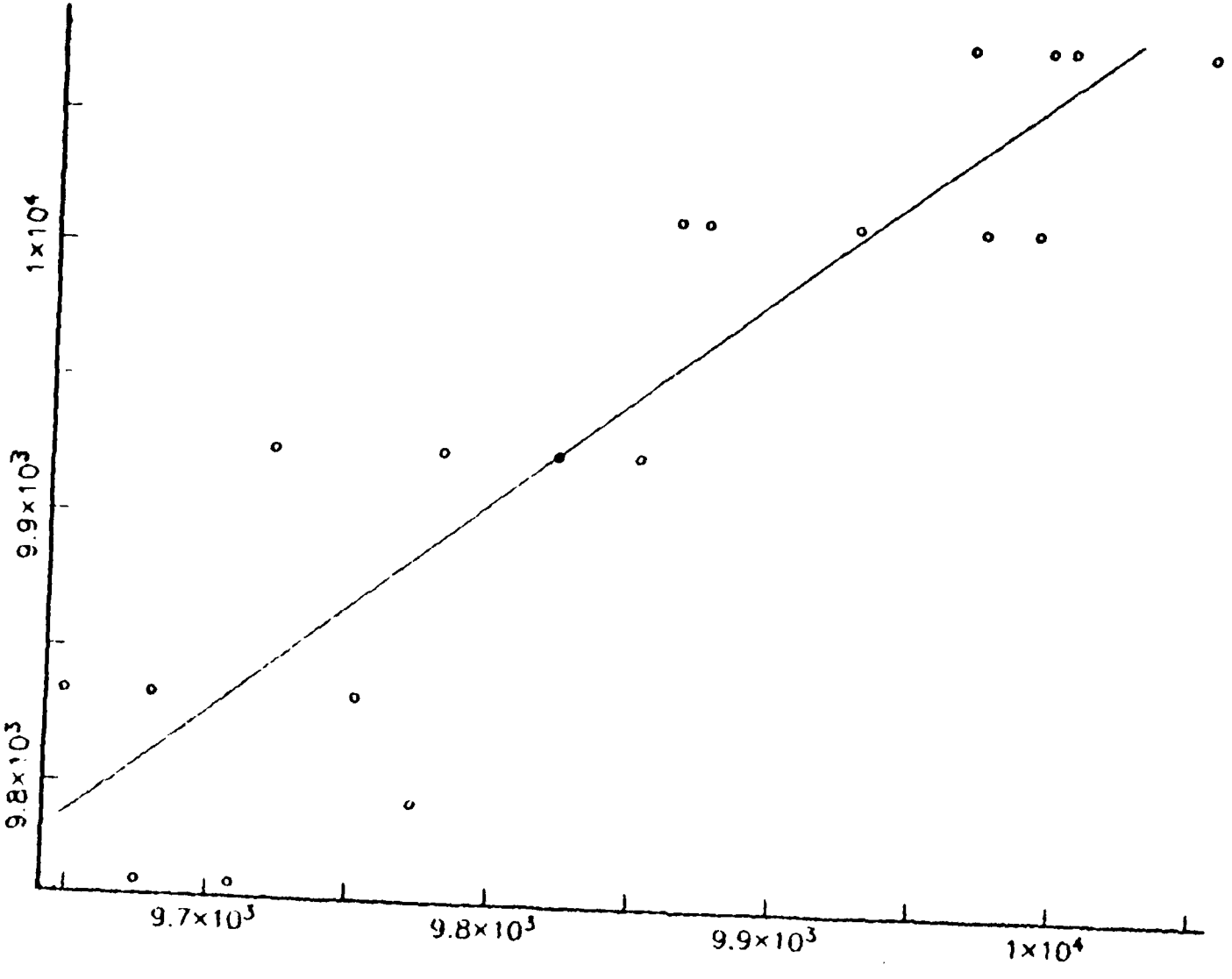


FIGURE 19

FORECASTED VALUES OF AMPLITUDE - STORM 2

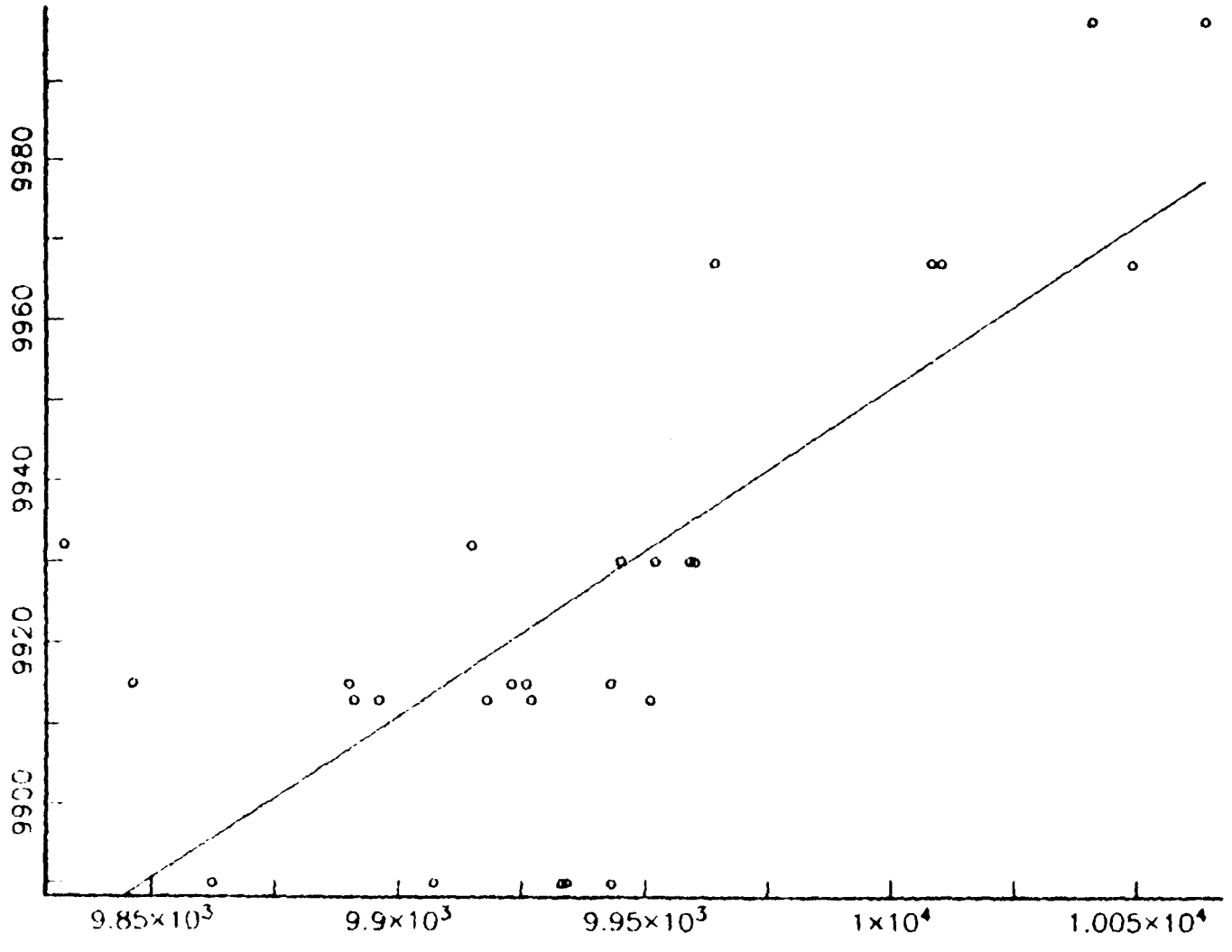


FIGURE 20

FORECASTED VALUES OF AMPLITUDE - STORM 10

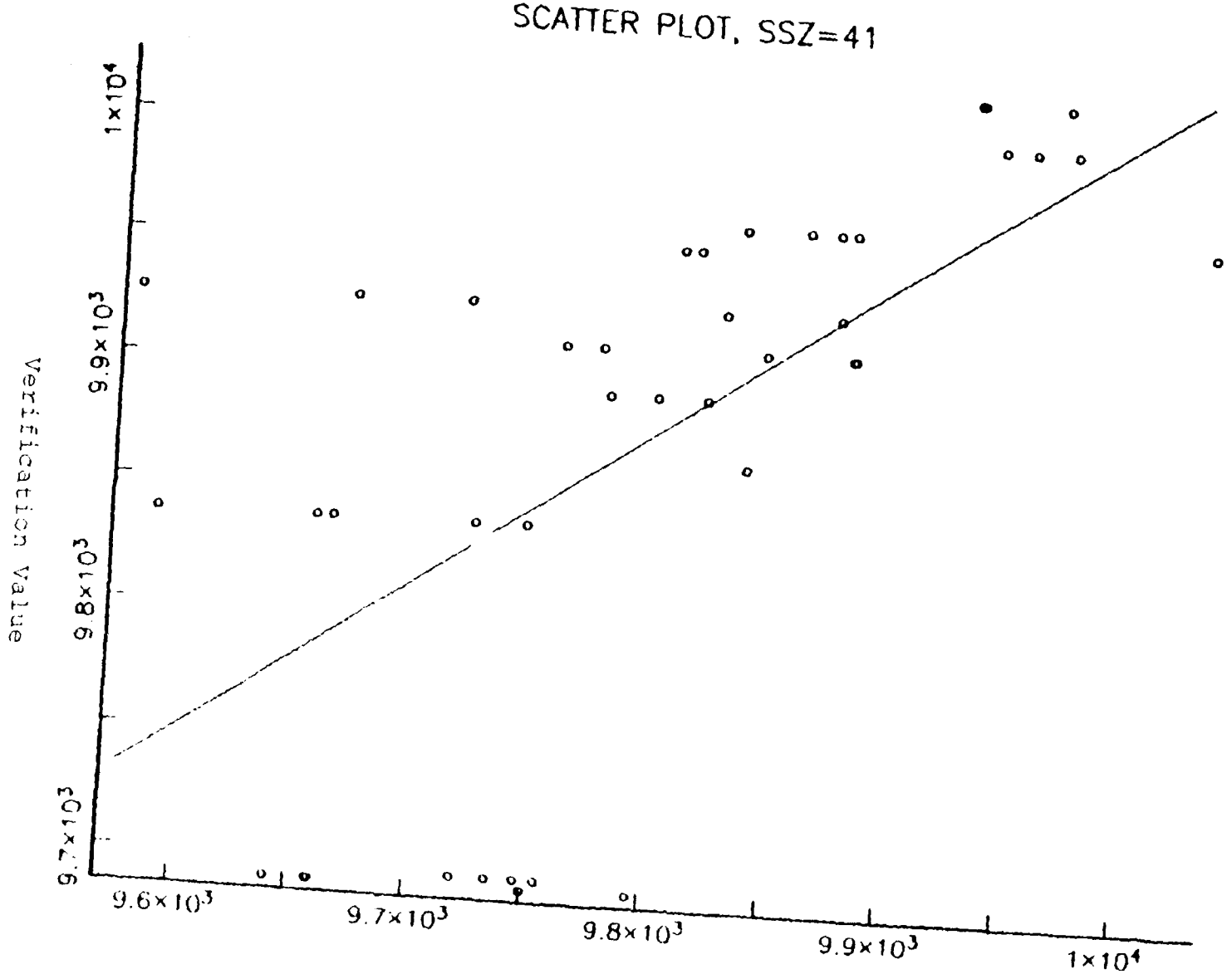


FIGURE 21
FORECASTED VALUES OF AMPLITUDE - STORM 11

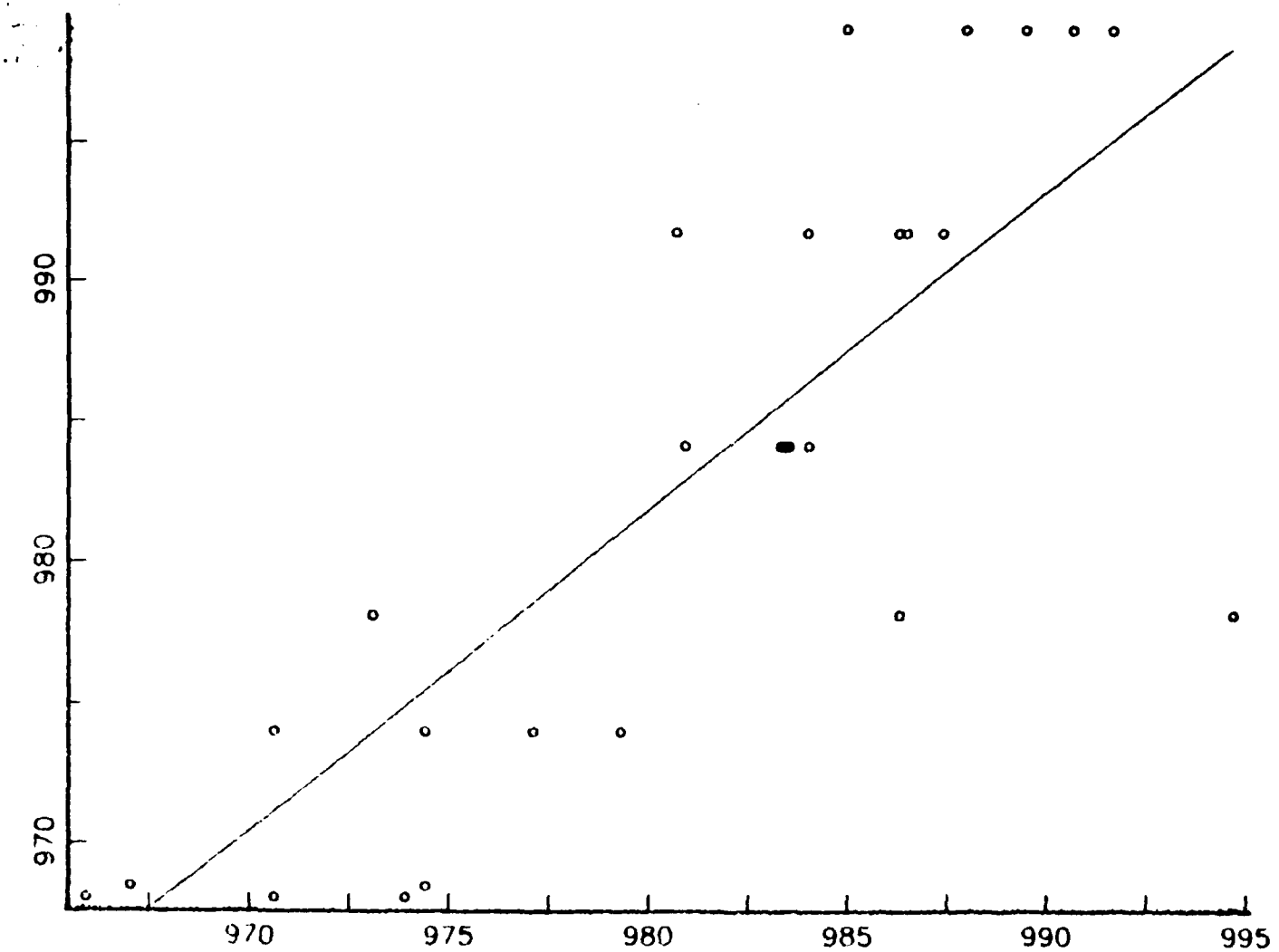


FIGURE 22

FORECASTED VALUES OF AMPLITUDE - STORM 20

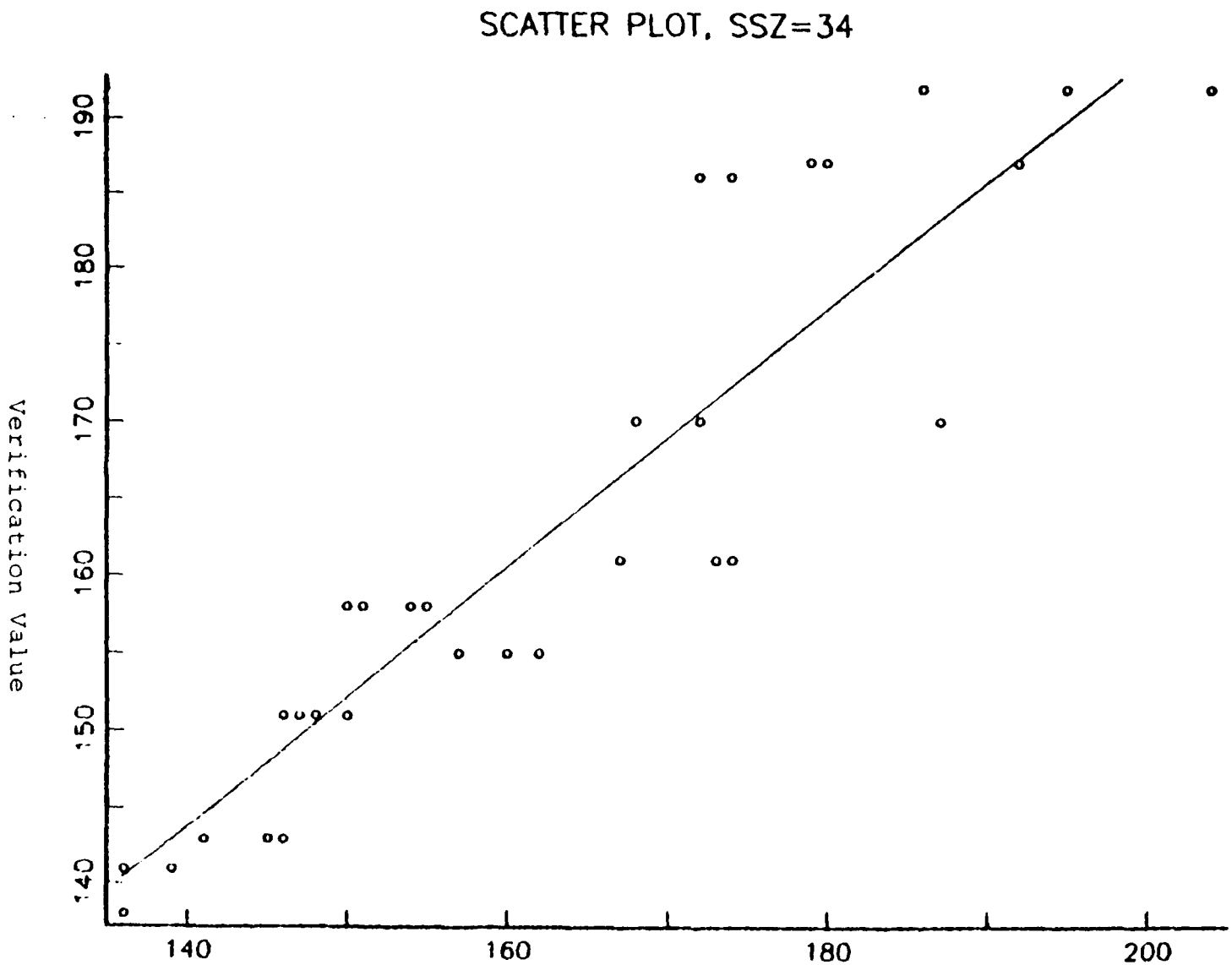


FIGURE 23

FORECASTED VALUE OF X_0 - STORM 4

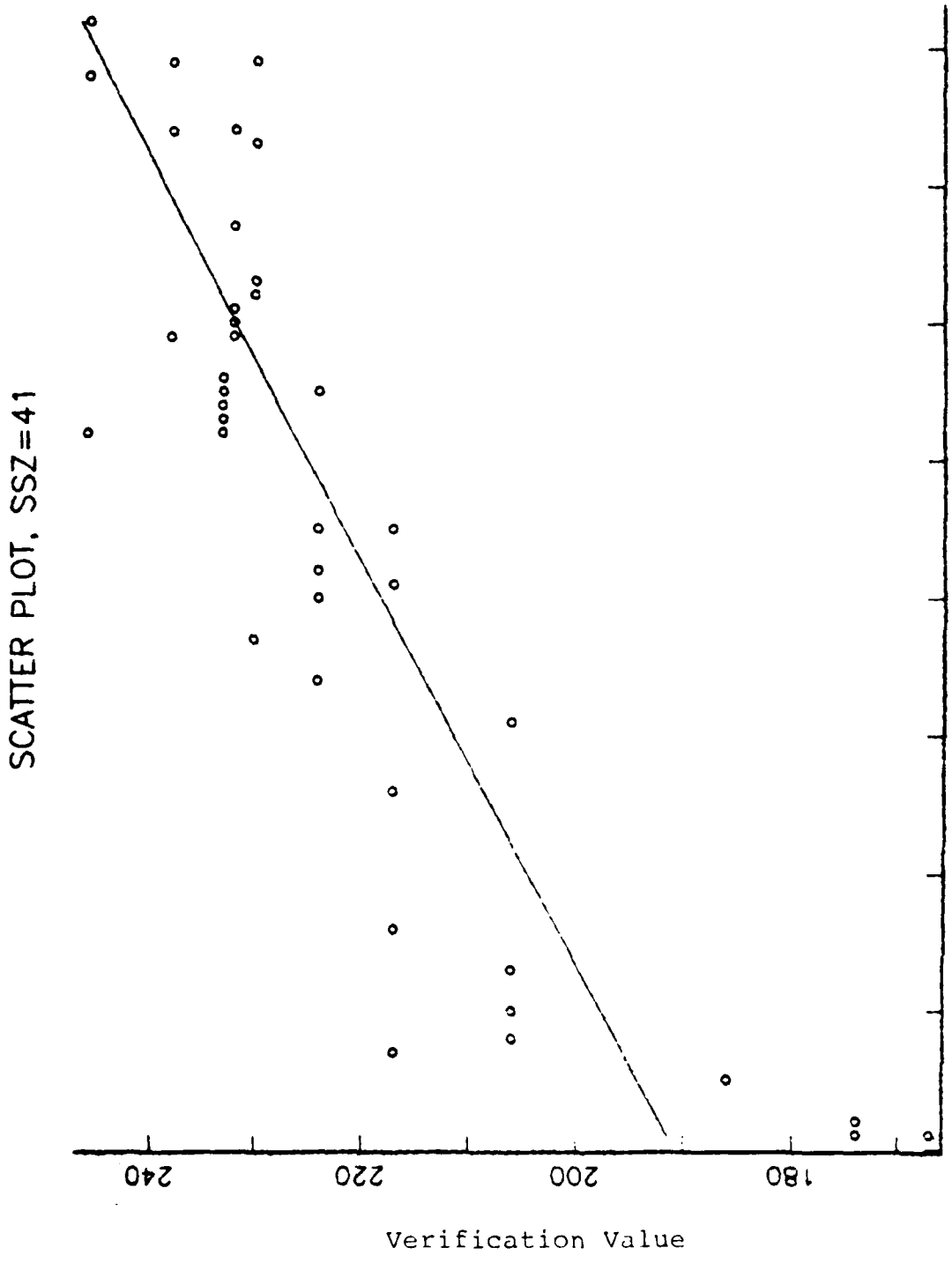


FIGURE 24

FORECASTED VALUE OF X_o - STORM 11

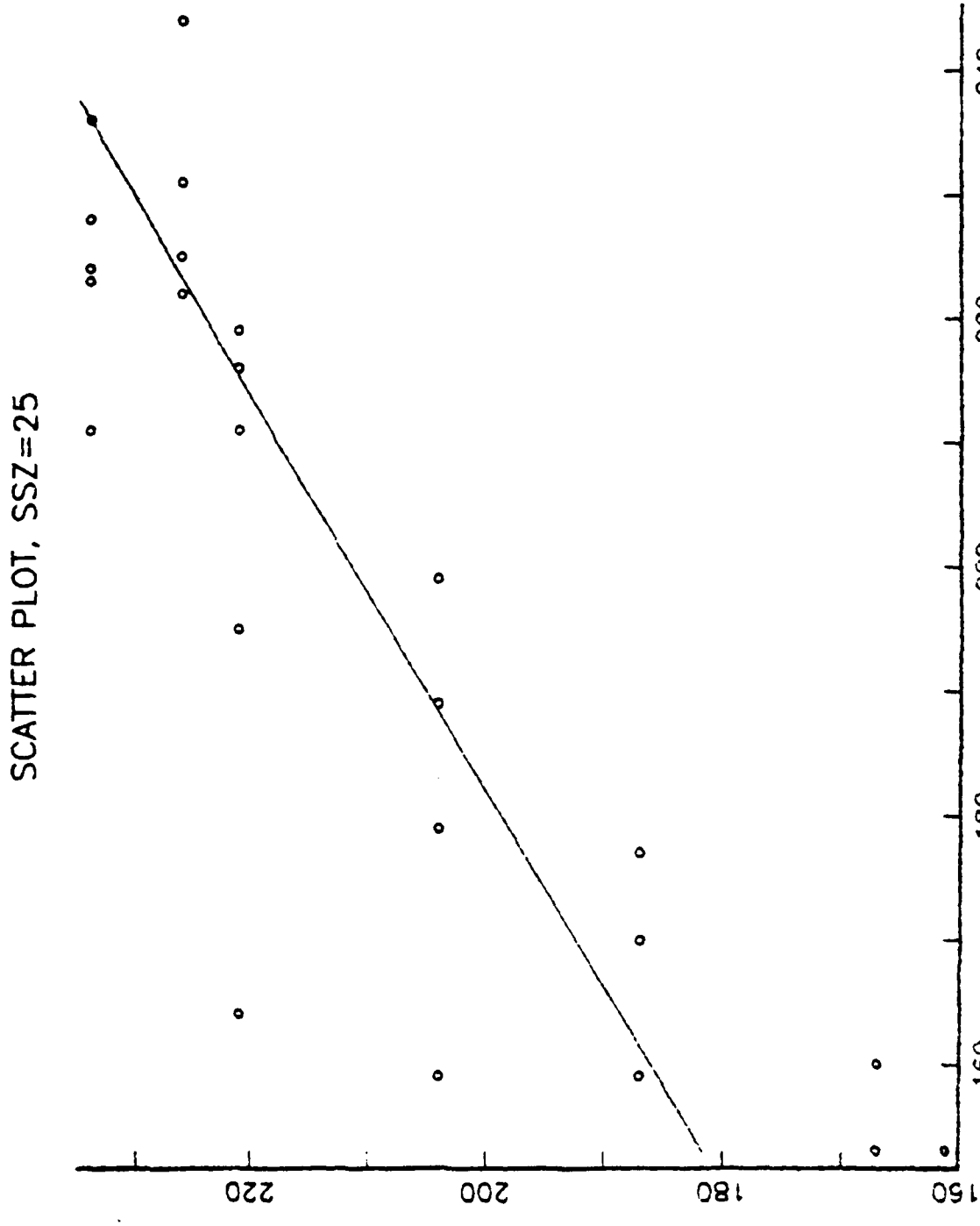


FIGURE 25
FORECASTED VALUE OF X_o - STORM 12

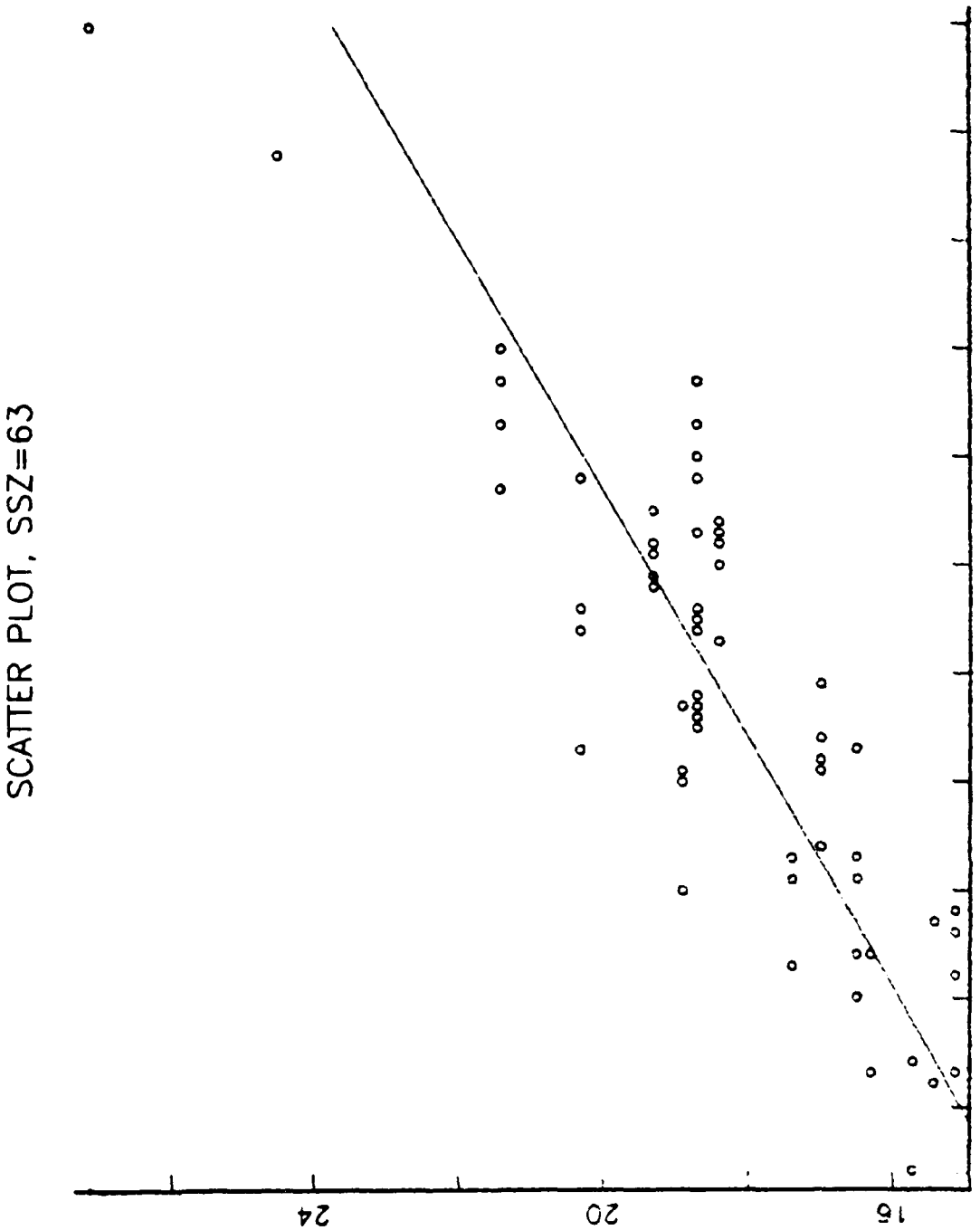


FIGURE 26
FORECASTED VALUE OF X_o - STORM 16

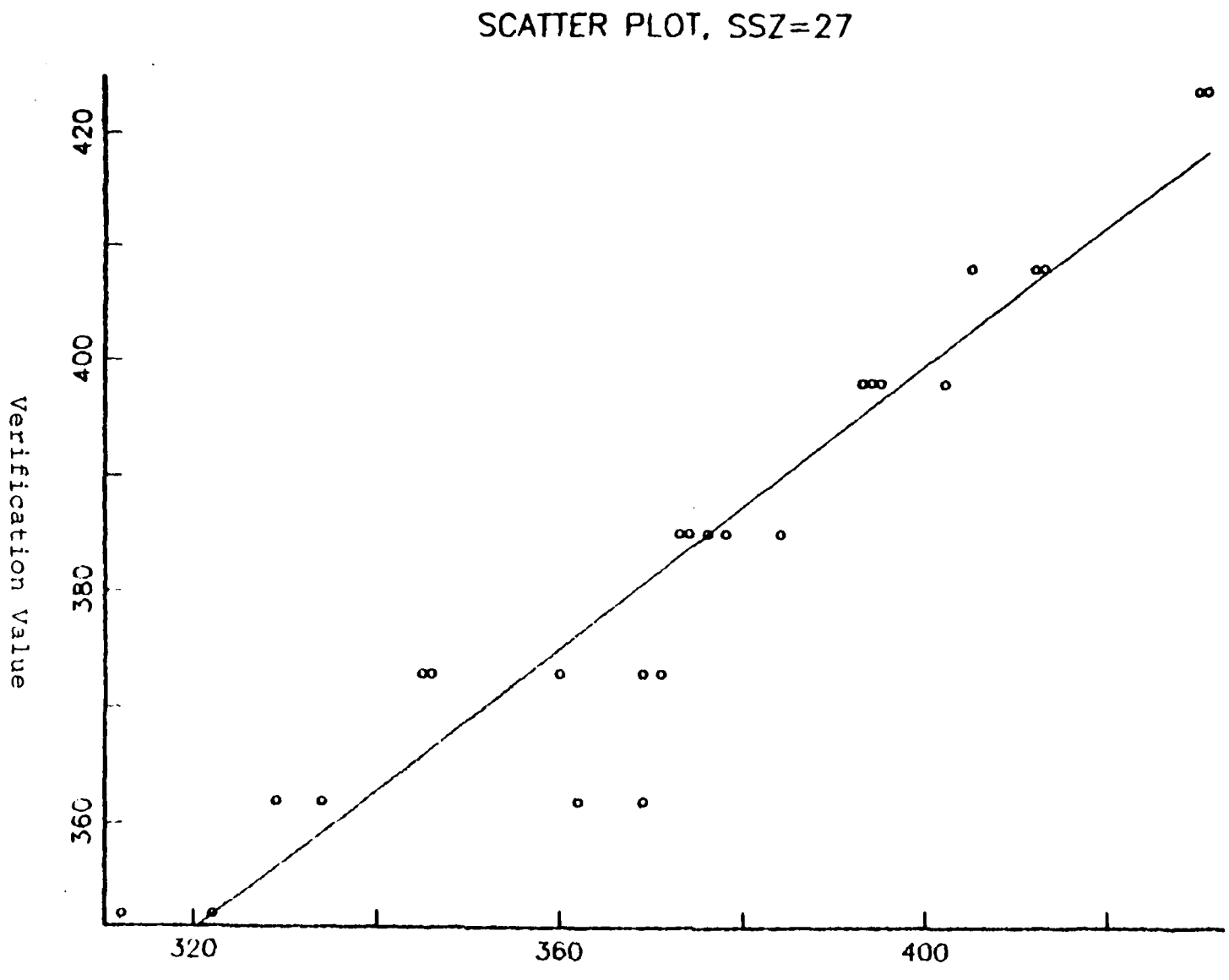


FIGURE 27

FORECASTED VALUES OF Y_o - STORM 10

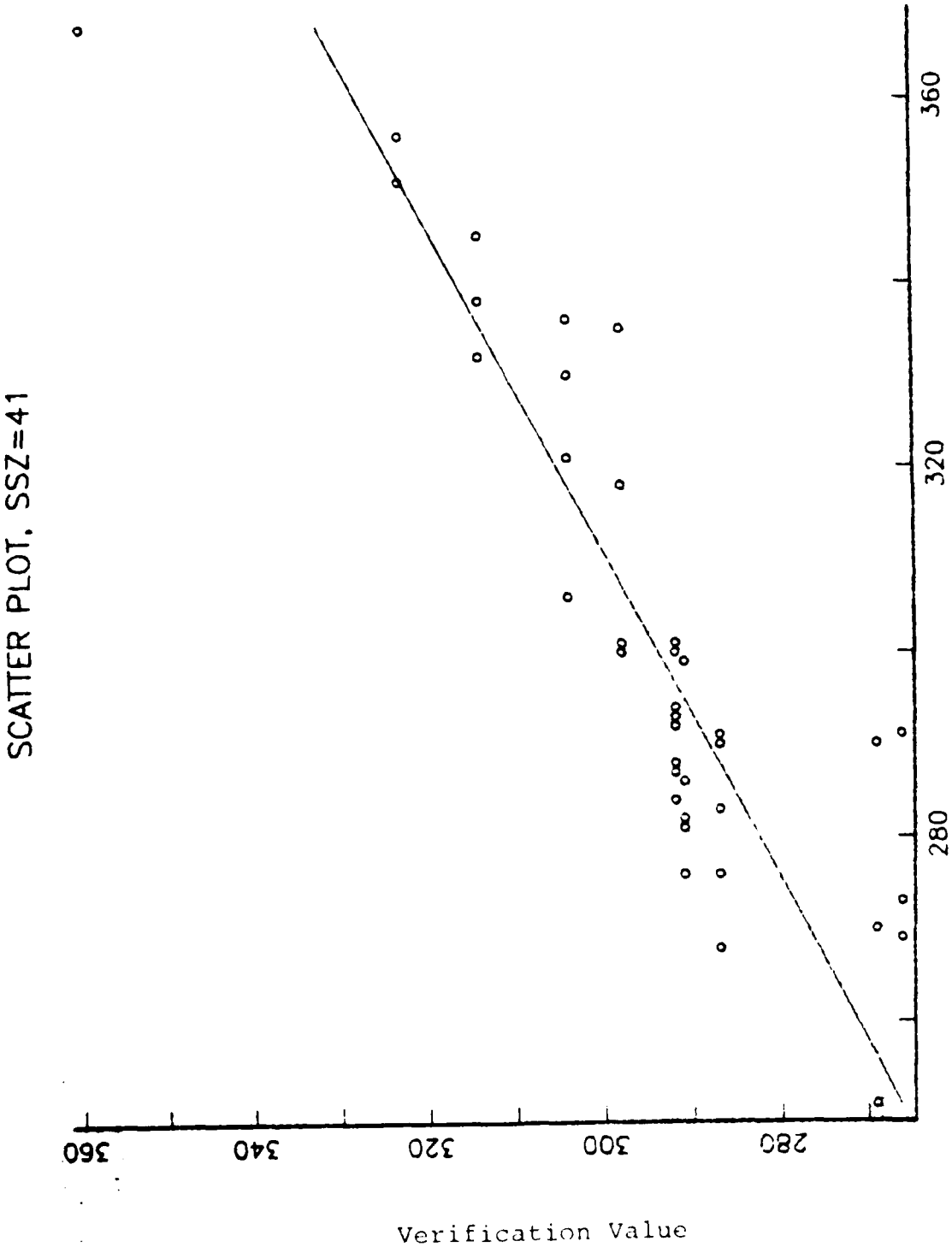


FIGURE 28

FORECASTED VALUES OF Y_o - STORM 11

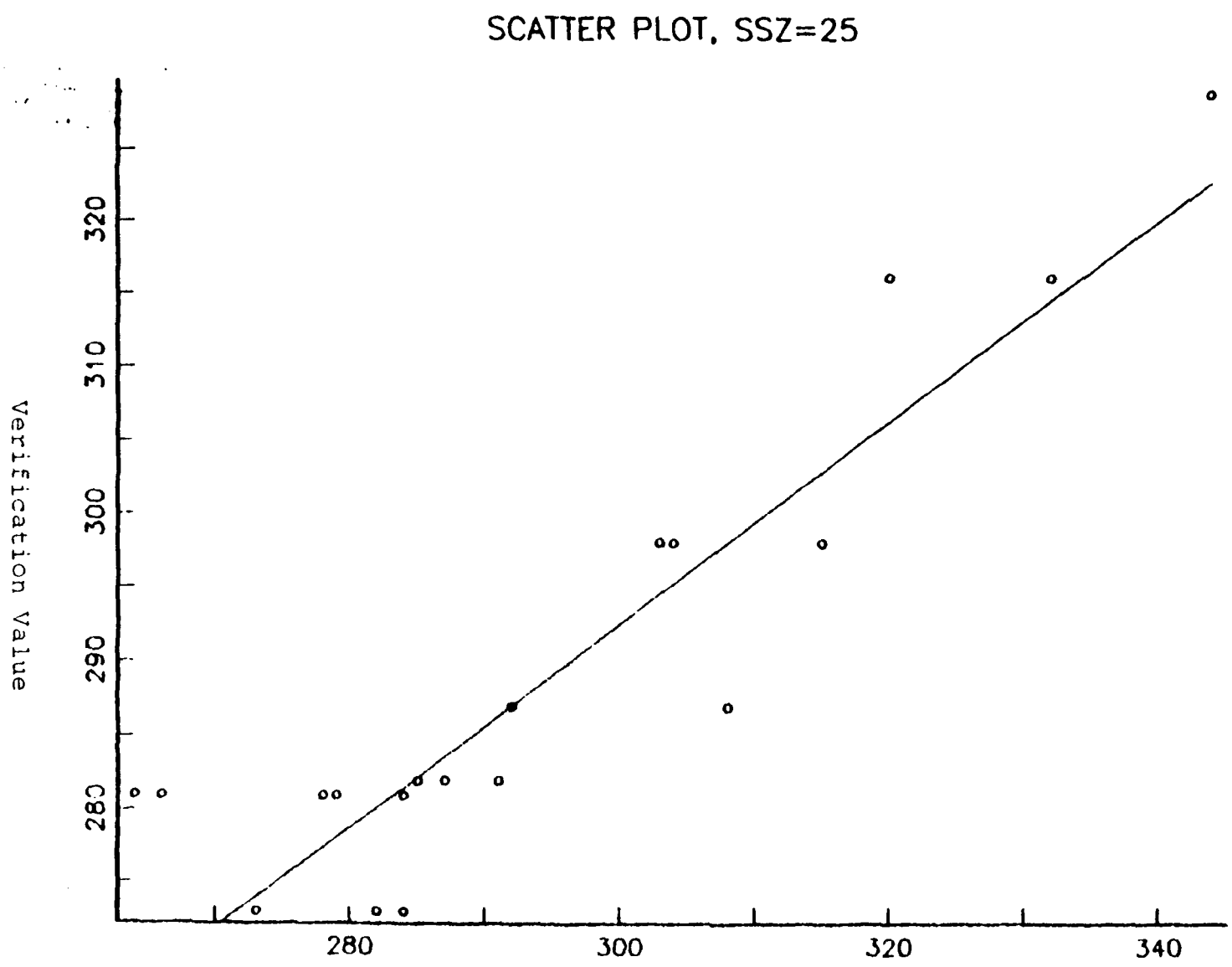


FIGURE 29

FORECASTED VALUES OF Y_O - STORM 12

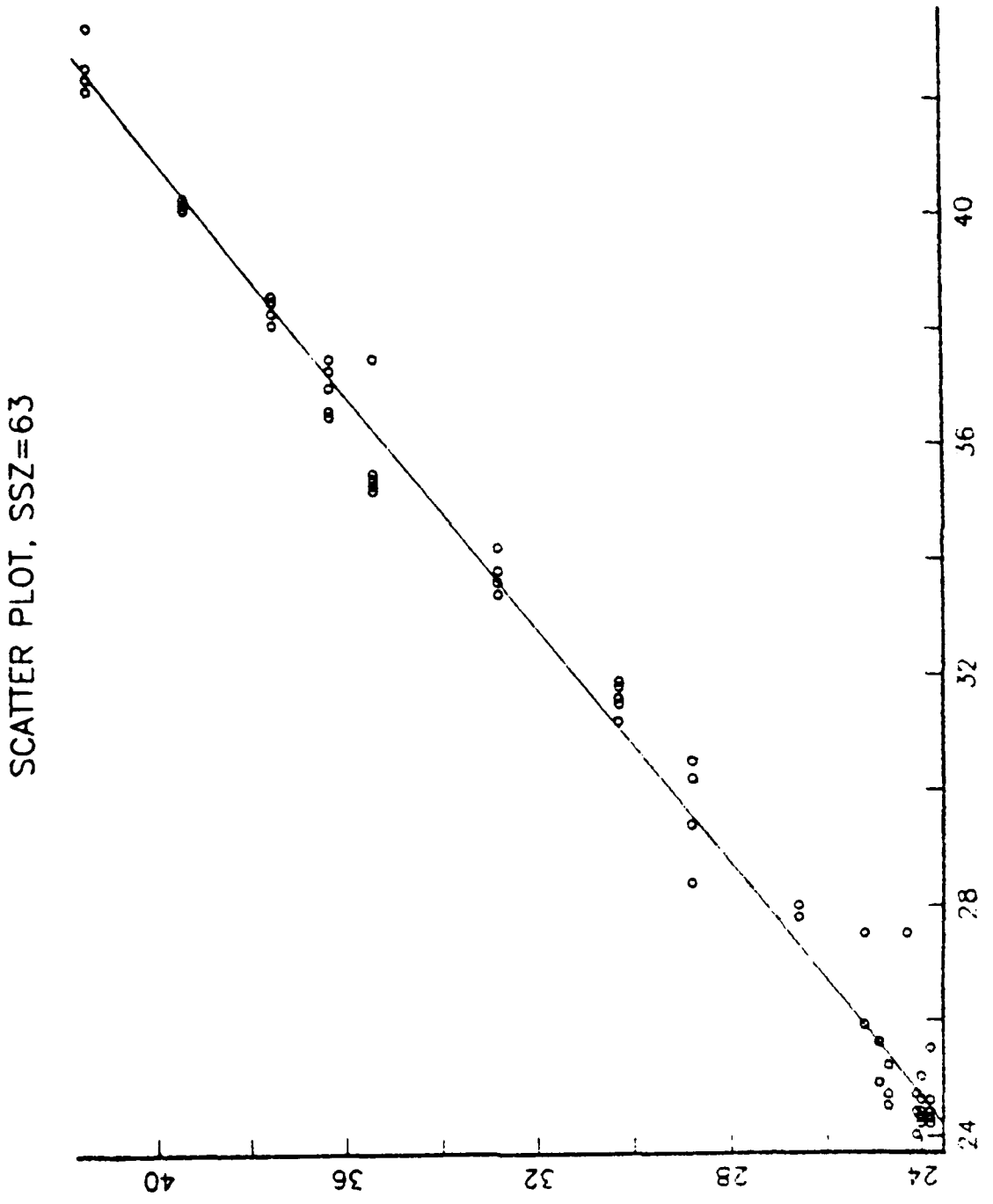


FIGURE 30

FORECASTED VALUES OF Y_o - STORM 16

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ALEXANDRIA, VIRGINIA 22214

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY (5)
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